AUGUST 1978 2-55910/8R-3483

(NASA-CR-150894) LOW ENERGY STAGE STUDY. VOLUME 2: REQUIREMENTS AND CANDIDATE PROPULSION MODES (Vought Corp., Dallas, Tex.) 144 p HC A07/MF A01 CSCL 22A

N79-15131

Unclas
G3/12 43294

# LOW ENERGY STAGE STUDY

## VOLUME II

## REQUIREMENTS AND CANDIDATE PROPULSION MODES

FOR NASA
MARSHALL SPACEFLIGHT CENTER

VOUGHT CORPORATION
an LTV company

AUGUST 1978

2-55910/8R-3483

# LOW ENERGY STAGE STUDY

## VOLUME II

## REQUIREMENTS AND CANDIDATE PROPULSION MODES

FOR NASA
MARSHALL SPACE FLIGHT CENTER

CONTRACT NAS8-32710
DPD 553 MA-04

VOUGHT CORPORATION
an LTV company

# F O R E W O R D

This $236,000 Low Energy Stage Study was performed by Vought Corporation under NASA Contract NAS8-32710 for Marshall Space Flight Center from September 1977 through August 1978. The prime objective of the study was to determine the most cost effective approaches for placing automated payloads into low energy Earth orbits. These payloads are injected into circular or elliptical orbits of different inclinations with energy requirements in the range of capability between that of the Space Shuttle standard orbit altitude (296 km) and of the Shuttle with a Spinning Solid Upper Stage - D (SSUS-D). The study results are documented in five volumes:

I. Executive Summary
II. Requirements and Candidate Propulsion Modes
III. Conceptual Design, Interface Analyses, Flight and Ground Operations
IV. Cost Benefit Analysis and Recommendations
V. Program Study Cost Elements and Appendices

The Vought Corporation study manager was Mr. J. M. Bean. Other key Vought participants were H. I. Knight, J. J. Banchetti, B. H. Fuller, B. J. Cathey, and C. D. Stephens.

The study was performed under the technical direction of C. C. Priest, Marshall Space Flight Center. Mr. M. Kitchens was the overall program manager at NASA Headquarters, Office of Space Transportation Systems.

Inquiries regarding the study should be addressed to the following:


- Claude C. (Pete) Priest
  NASA-Marshall Space Flight Center
  Attention: PS04
  Huntsville, Alabama 35812
  Telephone: (205)453-2791

- Jack M. Bean
  Vought Corporation
  P.O. Box 225907
  Dallas, Texas 75265
  Telephone: (214)266-4513

## ACKNOWLEDGEMENT

C. C. Priest, the NASA-MSFC contracting officer's representative, provided valuable guidance and direction throughout this Low Energy Stage Study.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (CONT'D)

## ABBREVIATIONS AND ACRONYMS

| | | |
|---|---|---|
| ACS | - | Attitude Control System |
| A/D | - | Analog to Digital |
| AGE | - | Aerospace Ground Equipment |
| AK | - | Apogee Kick |
| AKM | - | Apogee Kick Motor |
| AMPTE | - | Active Magneto Spinning Particle Tracer |
| ANT | - | Antenna |
| ASE | - | Airborne Support Equipment |
| BER | - | Bit Error Rate |
| BITE | - | Built-In Test Equipment |
| C&DH | - | Communication and Data Handling |
| CER | - | Cost Estimating Relationship |
| c.g. | - | Center of Gravity |
| CITE | - | Cargo Integrated Test Equipment |
| cm | - | Centimeter |
| COR | - | Contracting Officers Representative |
| C/O | - | Checkout |
| C&W | - | Caution and Warning |
| CWE | - | Caution and Warning Electronics |
| db | - | Decibel |
| DDT&E | - | Design Development Test and Evaluation |
| DMU | - | Deployment Mechanism Unit |
| DOD | - | Department of Defense |
| DVT | - | Development Test |
| EDS | - | Empirical Data Sets |
| EED | - | Electro-explosive Device |
| EIRP | - | Effective Isotrophic Radiated Power |
| ELV | - | Expendable Launch Vehicle |
| EMI | - | Electro-Magnetic Interference |
| ERBS | - | Earth Radiation Budget Satellite |
| ESH | - | Explosive Safe Area |
| ETR | - | Eastern Test Range |
| EVA | - | Extravehicular Activity |
| FSS | - | Flight Support System for MMS |
| GCU | - | Guidance and Control Unit |
| GHe | - | Gaseous Helium |
| GPC | - | General Purpose Computer |
| GPS | - | Global Positioning Satellite |
| GSE | - | Ground Support Equipment |
| GSFC | - | Goddard Space Flight Center |
| HMF | - | Hypergolic Maintenance Facility |
| Hz | - | Hertz (cycles) |

## ABBREVIATIONS AND ACRONYMS (CONT'D)

| | | |
|---|---|---|
| ICD | - | Interface Control Document |
| ICU | - | Ignition Control Unit |
| I/O | - | Input/Output |
| IRIG | - | Inter-Range Instrumentation Group |
| ISU | - | Inertial Stabilization Unit |
| IUS | - | Inertial Upper Stage |
| JSC | - | Johnson Space Center |
| Kbps | - | Kilo bits per second |
| Kg | - | Kilogram |
| KSC | - | Kennedy Space Center |
| km | - | Kilometers |
| Lbf | - | Pound-Force |
| Lbs | - | Pounds |
| L/D | - | Length/Diameter |
| LES | - | Low Energy Stage |
| LH | - | Left Hand |
| MCDS | - | Multifunction CRT Display System |
| MCEM | - | Mechanical Cost Evaluation Methodology |
| MDM | - | Multiplexer-Demultiplexer |
| MFBA | - | Mobile Flat Bed Assembly |
| MHz | - | Mega hertz |
| MLI | - | Multilayer Insulation |
| m | - | Meters |
| MMH | - | Monomethylhydrazine |
| MMS | - | Multimission Modular Spacecraft |
| MMSE | - | Multimission Support Equipment |
| mps | - | Meters per second |
| MSDP | - | Mission Station Distribution Panel |
| MSFC | - | Marshall Space Flight Center |
| N | - | Newtons |
| nm | - | Nautical Mile |
| NSI | - | NASA Standard Initiator |
| O&CF | - | Operations and Control Facility |
| OMS | - | Orbiter Maneuvering Subsystem |
| OPEN | - | Origin of Particles in the Earth Neighborhood |
| OPAF | - | Ordnance Payload Assembly Facility |
| OPF | - | Orbiter Processing Facility |

ABBREVIATIONS AND ACRONYMS (CONT'D)

| | | |
|---|---|---|
| PCM | – | Pulse Code Modulation |
| PCR | – | Payload Changeout Room |
| PCU | – | Power Control Unit |
| PDI | – | Payload Data Interleaver |
| PGHM | – | Payload Ground Handling Mechanism |
| PK | – | Perigee Kick |
| PKM | – | Perigee Kick Motor |
| P/L | – | Payload |
| PRICE | – | Programmed Review of Information for Costing and Evaluation |
| PSDP | – | Payload Station Distribution Panel |
| PSI | – | Pressure Systems, Inc. |
| psi | – | Pounds per square inch |
| psig | – | Pounds per square inch, gage |
| RCS | – | Reaction Control System |
| RCVR | – | Receiver |
| RF | – | Radio Frequency |
| RFI | – | Radio Frequency Interference |
| RHCP | – | Right Hand Circular Polarization |
| RMS | – | Remote Manipulator System |
| R | – | Retrieval |
| rpm | – | Revolution per minute |
| SAEF | – | Spacecraft Assembly Encapsulating Facility |
| SCOOP | – | System Technology Office Confirmation of Optical Phenomenology |
| S/DIU | – | Signal/Data Interface Unit |
| SDP | – | Special Defense Program |
| Sec | – | Second |
| SIO | – | Serial Input/Output |
| SOP | – | Standard Operating Procedure |
| SPST | – | Single Pole Single Throw |
| SRB | – | Solid Rocket Booster |
| SRM | – | Solid Rocket Motor |
| SSUS-A | – | Spinning Solid Upper Stage - Atlas Class |
| SSUS-D | – | Spinning Solid Upper Stage - Delta Class |
| STDN | – | Space Tracking and Data Network |
| STS | – | Space Transportation System |
| TCD | – | Technical Characteristics Data |
| Td | – | The Time (months) to design and develop or produce a WBS item |
| TIG | – | Tungsten Inert Gas |
| TM | – | Telemetry |

ABBREVIATIONS AND ACRONYMS (CONT'D)

| | | |
|---|---|---|
| TRS | – | Teleoperator Retrieval System |
| Ts | – | The Lead Time (months) measured from the start of cost accured for the item to the launch milestone date, for the initial item |
| TSP | – | Twisted Shielded Pair |
| Tx | – | Transmitter |
| UARS | – | Upper Atmosphere Research Satellite |
| UDS | – | Universal Documentation System |
| VPF | – | Vertical Processing Facility |
| VPHD | – | Vertical Payload Handling Device |
| V | – | Revisit |
| WBS | – | Work Breakdown Structure |
| WTR | – | Western Test Range |
| $\Delta V$ | – | Delta Velocity |

# 1.0 INTRODUCTION

The Low Energy Stage Study provides a thorough and objective derivation and evaluation of the most cost-effective approaches for placing NASA Space Transportation System Orbiter automated payloads into low energy Earth orbits. A brief review of the study background and objectives is followed by the overall study guidelines and assumptions and an explanation of the report organization.

## 1.1 BACKGROUND

In early 1977 the baseline Space Transportation System (STS) manifests projected many automated payloads to be delivered to Earth orbit with energy requirements lower than the capability of the smallest of the Shuttle upper stages planned at that time. This smallest stage was the Spinning Solid Upper Stage - Delta Class (SSUS-D). Additionally, at that time the STS planning had not addressed space transportation accommodations for Scout expendable launch vehicle class payloads. The low mass (usually less than 200 kg) does not allow efficient economic utilization of the planned Shuttle upper stage concepts. A Shuttle small low energy upper stage for both of these classes of payloads, that provides perigee and apogee propulsion and attitude control, can be a cost-effective concept if multiple payload delivery capabilities per Shuttle launch can be achieved through innovative packaging arrangements in the cargo bay or if minimum length stage concepts are developed. The Shuttle user charge policy provides a cost driver toward short and lightweight cargo bay installations, especially for smaller payloads. The cost effectiveness of Shuttle/small low energy upper stage concepts compared with payload delivery by the Orbiter/Orbital Maneuvering Subsystem (OMS), currently planned Shuttle upper stages, existing expendable launch vehicle upper stages, and the Scout launch vehicle required further assessment.

## 1.2 STUDY OBJECTIVES

The prime objective of the study was to determine the most cost-effective approaches for placing automated payloads into low energy Earth orbits. These payloads are injected into circular or elliptical orbits of different inclinations with energy requirements in the range of capability

between that of the Shuttle standard orbit altitude 296 km (160 nm) and of the Shuttle with a SSUS-D. This primary objective was to be attained by meeting the following specific objectives:

- Define payload/mission requirements, a set of reference missions representative of these requirements, and upper stage design criteria necessary for initial definition and screening of cost effective Shuttle upper stage approaches capable of accommodating low energy missions. Requirements were drawn from a low energy payload mission model supplied by NASA.
- Describe and analyze Shuttle upper stage design approaches, cargo bay packaging schemes, and interface concepts for cost effectively accommodating low energy missions. Define supporting systems, integration and operations. Evaluate, compare and select propulsion approaches for conceptual design.
- Perform conceptual design and systems analysis of selected payload delivery approaches. Define the impact of low energy stage (LES) characteristics on payload design trends.
- Determine payload, low energy stage, and Shuttle Orbiter interface requirements and their impact on low energy propulsion approaches.
- Determine ground and flight operations requirements and their impact on low energy propulsion approaches.
- Perform cost/benefit comparison of conceptually designed propulsion approaches with currently planned Shuttle upper stage systems, Shuttle with OMS, and the Scout launch vehicle.
- Complete a development and implementation plan for the recommended concept for accommodating the low energy payloads of the STS payload mission

model and the low energy regime they represent. Incorporate cost and schedule projections, test requirements, and supporting technology requirements sufficient to support future NASA program decisions.

## 1.3 GUIDELINES AND ASSUMPTIONS

The following basic guidelines and assumptions were used in the study.

- The payload mission models, Shuttle user charge policy, and low energy regime mass-energy envelope data were provided by NASA.
- Investigation was limited to expendable propulsion systems with the exception of the Teleoperator Retrieval System which is being considered for the Skylab Boost Mission.
- Electric propulsion systems were excluded from the study.
- Liquid and solid forms of chemical propulsion and hybrids were considered in the study.
- Solid propellants were limited to Class 2.
- Operational period for comparison analysis of propulsion systems begins in early 1980's and extends through 1991.
- Space Transportation System physical and operational data are as defined by JSC document 07700 Volume XIV, Revision E.
- Applicable data and results from other government sponsored studies are used in this study.
- Study cost data is in 1977 dollars.

## 1.4 REPORT ORGANIZATION

The report is organized to present the results of the study in the order in which the work was accomplished. The study began with a requirements definition (Task 1) (see Figure 1.1) that established a set of

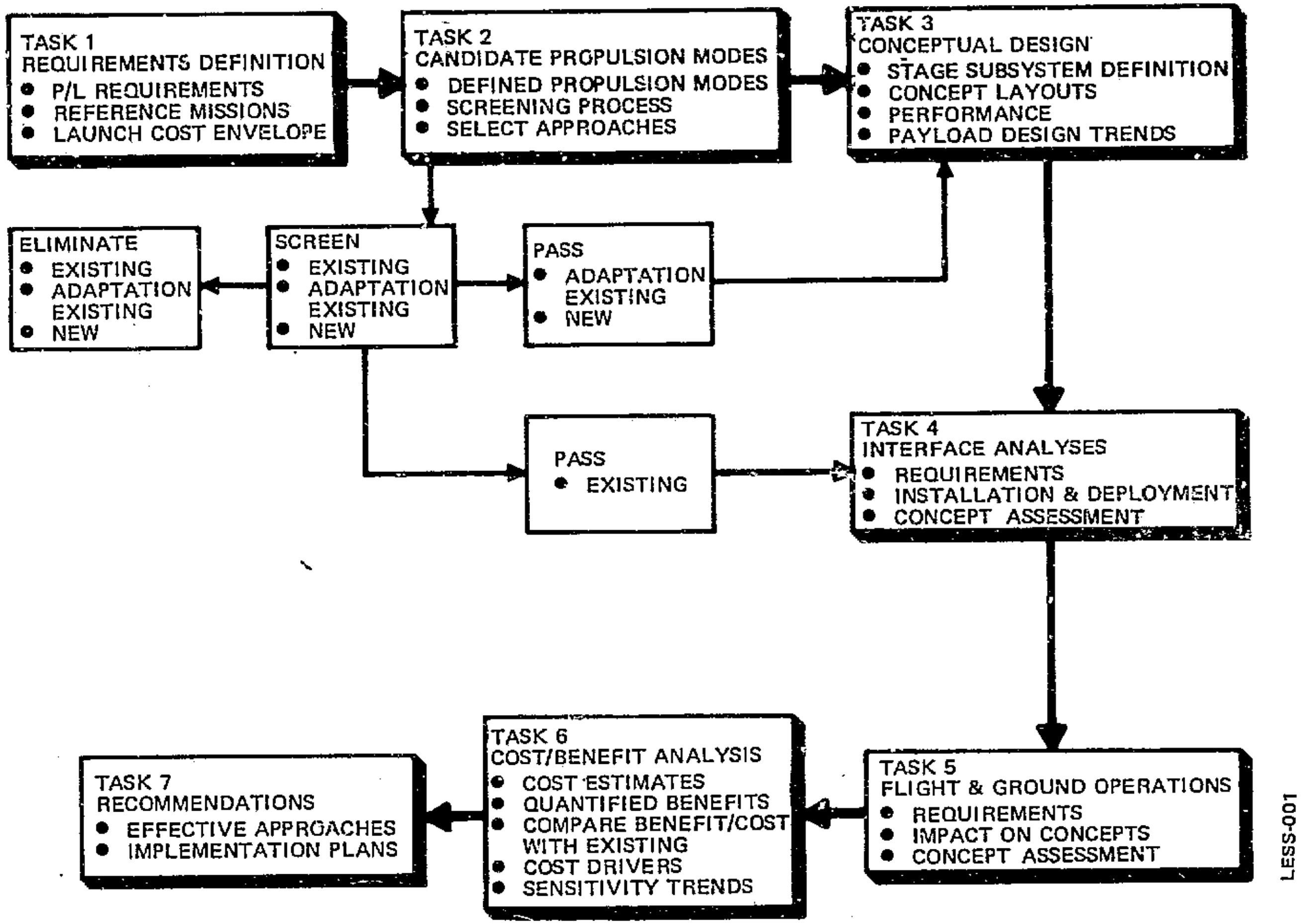



**FIGURE 1.1 STUDY FLOW**

reference missions and payload characteristics representative of a NASA defined payload/mission model. Launch cost envelopes were defined. Candidate propulsion modes were defined (Task 2) which accommodated the reference payload/missions. A screening process was developed, based on cost and benefits, and used to screen these candidates. Some were eliminated; adaptations of existing/planned propulsion systems and new approaches were selected for conceptual design in Task 3; screened existing/planned systems flowed to Tasks 4 and 5 for assessment related to Shuttle interface and flight and ground operations, along with the concepts from Task 3. Some surviving existing systems, such as Orbiter/OMS, were carried directly into the cost/benefit analysis (Task 6). The conceptual design effort of Task 3 consisted of stage subsystem refinement and selection, concept design, performance evaluation to assure meeting the requirements of a new payload mission model provided by NASA, cost/schedule definition, integral propulsion concept analysis, and definition of impact on payload design trends. Tasks 4 and 5 assessed the surviving concepts from Tasks 2 and 3 relative to Orbiter interface and ground and flight operations. Costs and quantified benefits of the concepts from Task 3 and the existing systems from Task 2 were defined in Task 6. Scenarios of those concepts which met the missions requirements of the payloads of a revised mission model were defined and life cycle costs developed. These scenarios were ranked and the most cost effective approaches recommended in Task 7 along with implementation plans to support NASA program decisions.

The report is contained in five volumes and organized as follows:

| VOLUME | TASKS | CONTENTS |
|---|---|---|
| I | - | Executive Summary |
| II | 1<br>2 | Requirements Definition<br>Candidate Propulsion Modes |
| III | 3<br>4<br>5 | Conceptual Design<br>Interface Analysis<br>Ground and Flight Operations |
| IV | 6<br>7 | Cost Benefit Analysis<br>Recommendations |
| V | - | Program Study Cost Elements |

A listing of references applicable throughout the report is included at the end of each volume.

## 2.0 TASK 1: REQUIREMENTS DEFINITION

The Low Energy Stage (LES) Study is an evaluation of propulsion approaches to accommodate payloads within the low energy regime. Initial definition of this regime and the requirements for the study were embodied in a payload mission model furnished by NASA. This model, covering 129 launches, was examined and compared against the Space Transportation System Shuttle standard orbit inclinations and a Shuttle launch site implementation schedule provided by NASA. Based on this examination and comparison a set of six reference missions were defined in terms of spacecraft weight and velocity requirements to deliver the payload from a 296 km circular Shuttle standard orbit to the spacecraft's planned orbit. Payload characteristics and requirements representative of the model payloads included in the regime bounded by each of the six reference missions were determined. A set of launch cost envelopes were developed and defined based on the characteristics of existing/planned Shuttle upper stages and expendable launch systems in terms of launch cost and velocity delivered. These six reference missions were used to define the requirements for the candidate propulsion modes which were developed and screened (Task 2) to determine the propulsion approaches for conceptual design (Task 3). A revision of the payload mission model, which incorporated the payloads of the Space Transportation System "487" model of 1978, was furnished later in the study by NASA and was used as the payload mission requirements for Task 3 through 6 (Volumes III and IV). This revised model is presented in Volume III, paragraph 4.1.

## 2.1 PAYLOAD MISSION MODEL

The payload mission model used in this volume of the study was developed by Battelle Columbus Laboratories and provided by NASA-MSFC Low Energy Stage Study Contracting Officer Representative (COR) during the first month of the study. Missions within the low energy regime include a variety of payloads from small, Scout-class automated spacecraft to large free-flying laboratories and observatories. Destination orbits range from altitudes of a few hundred kilometers to a few thousand kilometers or more with inclinations from zero to more than 100 degrees. Geosynchronous transfers are not included in the model.

Candidate payloads for this low energy model were selected by Battelle using the National Space Transportation System (STS) Payload Model of September 1976 (Reference 1), the STS Traffic Manifest 1980-1991 (Reference 2) and the NASA Payload Model Generic Payload Descriptions (Reference 3). Battelle augmented and updated these data with information provided by cognizant NASA personnel based on recently completed 5-year planning activities for Fiscal years 1979 through 1983 (References 4 and 5). The Battelle Outside Users Payload Model was the source for non-NASA/non-DoD missions (Reference 6). Battelle also included candidate DoD missions in the model.

### 2.1.1 Model Description

The payload mission model, Table 2-I, covers a period extending from 1980 through 1991 and includes missions sponsored by NASA, U.S. Government/Civil organizations, DoD and foreign organizations. The payloads are identified by their mission names and their generic payload codes, where appropriate. The mission line items are numbered sequentially and are referred to by these numbers in this Volume. Data shown for these missions are Battelle estimates of annual launch rate and schedule, mass and size of the payloads, the currently planned launch system, the perigee, apogee and inclination of the destination orbit.

2.1.1.1 NASA Payloads - The NASA payloads shown in Table 2-I include a total of 32 mission line items with a total of 75 payloads of which nine are Scout payloads, 37 are small to intermediate size automated spacecraft (SES, SSO, SSF, ASF and AIF, generic payload codes from Reference 3) and 29 are intermediate to large free-flying laboratories and observatories (SIO, SLO, LSO, STI and STL). Scout-launched NASA payloads are projected on the basis of:

- Planned or possible missions through the early 1980's (e.g., #12 Active Magnetospheric Particle Tracer Experiment, #13 Solar Mesosphere Explorer, #36 Transit).
- WTR launches prior to the Shuttle's introduction there (e.g., #23 Soil Moisture Sat., #40 Canadian Scientific).

# TABLE 2-I BASELINE LOW-ENERGY PAYLOAD MODEL

| | MISSION NAME | GENERIC/SSPD PAYLOAD CODE | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | TOTAL | SPACECRAFT PARAMETERS: MASS kg | SPACECRAFT PARAMETERS: LENGTH / DIA. m | LAUNCH VEHICLE | DELIVERY ORBIT: APOGEE / PERIGEE km | DELIVERY ORBIT: INCL. deg. | LAUNCH SITE | CODE | DATA SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NASA-OSS | | | | | | | | | | | | | | | | | | | | | | |
| | ASTROPHYSICS | | | | | | | | | | | | | | | | | | | | | | |
| 1. | COSMIC BACKGROUND EXPLORER (COBE) | SES or SSO AS-03 | | | | 1 | | | 1 | | | | | | 2 | 955* | 1/4 | STS | 900/900 | 97 | WTR | | 4,5 |
| 2. | EXTREME UV EXPLORER (EUVE) | SES or SSO - | | | | | 1 | | | | | | | | 1 | 240* | 1/4 | STS | 550/550 | 28.5 | ETR | | 4.5 |
| 3. | ASTRO. EXPLORER | SES OR SSO - | | | | | | | | | 1 | | | 1 | 2 | 300-1000 | 1/4 | STS | 400-600 CIRC | 28.5 | ETR | | 1-3 |
| 4. | ASTRO. EXPLORER | SES OR SSO - | | | | | | | | | | 1 | | | 1 | 300-1000 | 1/4 | STS | 400-600 CIRC | 56 | ETR | | 1-3 |
| 5. | ASTRO. EXPLORER | SES OR SSO - | | | | | | | | | | | 1 | | 1 | 300 1000 | 1/4 | STS | 400-600 CIRC | 90-100 | WTR | | 1-3 |
| 6. | GAMMA RAY ASTRONOMY OBS. (GRAO) | SIO/HE-08A | | | | 1 | | | 1 | | | | | | 2 | 8170 | 5.2/4.5 | STS | 460/460 | 28.5 | ETR | | 4,5,7 |
| 7. | COSMIC RAY OBS. (CRO) | SIO/ - | | | | | 1 | | | | 1 | | | | 2 | 8170 | 5.2/4.5 | STS | 460/460 | 56 | ETR | | 4,5,7 |
| 8. | X-RAY OBS. (XRO) | SLO/HE-01A | | | | | | 1 | | | | 1 | | | 2 | 10830 | 16/4.5 | STS | 460/460 | 28.5 | ETR | | 4,5,7 |
| 9. | 1.2-m X-RAY TELE. | SIO/HE-11A | | | | | | | | 1 | | | | 1 | 2 | 6240 | 10.2/4.5 | STS | 460/460 | 28.5 | ETR | | 4,5,7 |
| 10. | LARGE AREA MODULAR ARRAY OF REFLECTORS | SLO/ - | | | | | | | | | | | 1 | | 1 | 8320 | 12/4.5 | STS | 460/460 | 28.5 | ETR | | 4,5,7 |
| 11. | METER-CLASS UV TELE. | SLO/ - | | | | | | | | | | | | 1 | 1 | 8320 | 12/4.5 | STS | 460/460 | 28.5 | ETR | | 4,5,7 |
| | SOLAR TERRESTRIAL | | | | | | | | | | | | | | | | | | | | | | |
| 12. | ACTIVE MAGNETOSPHERIC PARTICLE TRACER (AMPTE) | (SCOUT) | △2 | | | | | | | | | | | | △2 | 66/54 | - | SCOUT | $8r_e$/200 $20r_e$/200 | 2.9 | SM | | 5,8,9 |
| 13. | SOLAR MESOSPHERE EXPLORER (SME) | (SCOUT) | | △1 | | | | △1 | | | | △1 | | | △3 | 150 | .5/0.8 | SCOUT OR STS | 500/500 | 96 | WTR | | 5,8,9 |
| 14. | SOLAR MAXIMUM F/O | SSF/SO-03 | | | | 1 | | | | 1 | | | | 1 | 3 | 1360 | 2/4.5 | STS | 575/575 | 28.5 | ETR | | 7 |
| 15. | UPPER ATMOSPHERE RESEARCH SAT. (UARS) | SSF/AP-03 | | | 1 | | | | 1 | | | | 1 | | 3 | 300 | 1.8/1.4 | STS | 500/500 | 28.5 | ETR | | 4,5,7 |
| 16. | UPPER ATMOSPHERE RESEARCH SAT. (UARS) | SSF/AP-03 | | | 1 | | | | 1 | | | | 1 | | 3 | 300 | 1.8/1.4 | STS | 500/500 | 90 | WTR | | 4,5,7 |
| 17. | ORIGIN OF PARTICLES IN EARTH NEIGHBORHOOD (OPEN) | SSF/AP-02 | | | | | | 1 | | | | | 1 | | 2 | 270 | 1.8/1.4 | STS | $8r_e$/300 | 28.5 | ETR | | 4,5,7 |
| 18. | SMALL OBSERVATORY CLASS (LIFE SCIENCE) | LSO/ - | | | | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 11 | 1500-2000 | 3/4 | STS | 400-500 CIRC | 28.5 | ETR | | 1-3 |

# TABLE 2-I BASELINE LOW-ENERGY PAYLOAD MODEL
(Continued)

| | MISSION NAME | GENERIC/SSPD PAYLOAD CODE | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | TOTAL | SPACECRAFT PARAMETERS MASS kg | SPACECRAFT PARAMETERS LENGTH DIA. m | LAUNCH VEHICLE | DELIVERY ORBIT APOGEE PERIGEE km | DELIVERY ORBIT INCL. deg. | LAUNCH SITE | CODE | DATA SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NASA-OA | | | | | | | | | | | | | | | | | | | | | | |
| 19. | MAGSAT F/O | (SCOUT) | | | △1 | | | | | △1 | | | | △1 | △3 | 170 | 1.5/ 0.8 | SCOUT or STS | 650/550 | 96 | WTR | | 5,8,9 |
| 20. | STEREOSAT | ASF/ – | | 1 | | | | | | | | | | | 1 | 200 | 1.5/ 1.0 | STS | 577/577 | 96.5 | ETR | | 4,5 |
| 21. | STEREOSAT F/O | ASF/ – | | | | | 1 | | | | | | | | 1 | 200 | 1.5/ 1.0 | STS | 577/577 | 96.5 | WTR | | 4,5 |
| 22. | EARTH RADIATION BUDGET SAT (ERBS) | ASF/EO-102 | | 1 | | | 1 | | | | | | | | 2 | 200 | 1.5/ 1.0 | STS | 500/600 | 50 | ETR | | 4,5 |
| 23. | SOIL MOISTURE SAT | ASF/EO-95 | | | △1 | | | | | | | | | | 1 | 170 | 1.5/ 0.8 | SCOUT | 600/600 | 97.5 | WTR | | 4,5 |
| 24. | DATA SAT | ASF/EO-98 | | | | 1 | | | | | | | | | 1 | 200 | 1.5/ 1.0 | STS | 1000/ 1000 | 59.5 | WTR | | 4,5 |
| 25. | SM. APPLICATION EXPL. | ASF/ – | | | | | | | | 1 | | 1 | | 1 | 3 | 200-1000 | 1/4 | STS | 500-1000 CIRC | 28.5-57 | ETR | | 4,5 |
| 26. | SM. APPLICATION EXPL. | ASF/ – | | | | | | | 1 | 1 | 1 | | 1 | | 4 | 200-1000 | 1/4 | STS | 500-1000 CIRC | 90-104 | WTR | | 4,5 |
| 27. | SEASAT B | AIF/OP-07A | | | | 1 | | | | | | | | | 1 | 2864* | 4.6/ 4.6/4 | ATLAS-F OR STS | 750/750* | 83/87* | WTR | | 1-3,7 |
| 28. | LANDSAT D/E F/O | AIF/EO-08A | | | | | | 1 | | | 1 | | | | 2 | 1610 | 7.2/ 2.2 | STS | 705/705 | 98.2 | WTR | | 1-3,7 |
| 29. | TIROS O/P | AIF/EO-12, -13 | | | | | 1 | | | | | 1 | | | 2 | 1430 | 6.5/ 2.2 | STS | 825/825 | 98.6 | WTR | | 1-3,7 |
| 30. | COASTAL ZONE MONITOR | AIF/ – | | | | | | 1 | | | 1 | | | | 2 | 1000 | 4.6/4 | STS | 600/600 | 65 | WTR | | 4,5,7 |
| 31. | INTERMEDIATE CLASS OBSERVATORIES | STI/ – | | | | | | 1 | | 1 | | 1 | | 1 | 4 | 4000-5000 | 3/4 | STS | 400-500 CIRC | 28.5 | ETR | | 1-3,7 |
| 32. | LARGE OBSERVATORIES | STL/ – | | | 1 | | 1 | | 1 | | 1 | | | | 4 | 8000-10000 | 9.1/ 4 | STS | 400-500 CIRC | 28.5 | ETR | | 1-3,7 |
| | SUBTOTAL, NASA | SCOUT | 2 | 1 | 2 | | | 1 | | 1 | | 1 | | 1 | 9 | | | | | | | | |
| | SUBTOTAL, NASA | SES, SSO, SSF, ASF, AIF | | 2 | 2 | 4 | 4 | 3 | 4 | 3 | 4 | 4 | 4 | 3 | 37 | | | | | | | | |
| | SUBTOTAL, NASA | LSO, SIO, SLO, STI, STL | | | 1 | 2 | 4 | 3 | 3 | 3 | 4 | 3 | 2 | 4 | 29 | | | | | | | | |

## TABLE 2-I BASELINE LOW-ENERGY PAYLOAD MODEL (Continued)

| | MISSION NAME | GENERIC/SSPD PAYLOAD CODE | LAUNCH SCHEDULE 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | TOTAL | SPACECRAFT PARAMETERS MASS kg | LENGTH DIA. m | LAUNCH VEHICLE | DELIVERY ORBIT APOGEE PERIGEE km | INCL. deg. | LAUNCH SITE | CODE | DATA SOURCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | U.S. GOV./CIVIL | | | | | | | | | | | | | | | | | | | | | | |
| 33. | OPERATIONAL SEASAT | AIF/ – | | | | | | | 2 | 1 | | | 2 | 1 | 6 | 3090 | 9/4 | STS | 808/808 | 108 | WTR | | 6 |
| 34. | NOAA (ITOS) F/O | AIF/ – | | | | | | | 1 | | 1 | | 1 | | 3 | 1090 | 1/4 | STS | 825/825 | 98.6 | WTR | | 6 |
| 35. | EARTH RESOURCES SAT (OPERATIONAL LANDSAT) | AIF/ – | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 8 | 700–900 | 1/4 | STS | 700/700 | 98.0 | WTR | | 6 |
| | DoD | | | | | | | | | | | | | | | | | | | | | | |
| 36. | TRANSIT F/O | SCOUT | △1 | △1 | △1 | △1 | | | | | | | | | △4 | 170–200 | 1.5/0.8 | SCOUT | 1000/1000 | 90 | WTR | | 6,8 |
| 37. | USAF SPACE TEST PROG | AIF/ – | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 910–1000 | 1/4 | STS | 500-1000 CIRC | 28.5–100 | ETR–WTR | | 5 |
| 38. | USAF METEOROLOGICAL SAT | AIF/ – | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1150 | 6/3 | STS | 750/750 | 98.4 | WTR | | 5 |
| | FOREIGN | | | | | | | | | | | | | | | | | | | | | | |
| 39. | SAN MARCO – $D_I$ | SCOUT | △2 | | | | | | | | | | | | △1 | 64 | 1.5/0.8 | SCOUT | $6r_e$/200 | 0-3 | SM | | 8,9 |
| 40. | CANADIAN SCIENTIFIC | SCOUT | | △1 | △1 | | | | | | | | | | △2 | 150–200 | 1.5/0.8 | SCOUT | 600/600 | 90 | WTR | | 6,12 |
| 41. | CANADIAN SCIENTIFIC | NOS/ – | | | | | 1 | | | | | | 1 | 1 | 3 | 200 | 1.5/0.8 | STS | 600/600 | 90 | WTR | | 6,12 |
| 42. | CANADIAN ALL-WEATHER MICROWAVE | NOM/ – | | | | | | 1 | | | | | | 1 | 2 | 2040 | 1.5/4/3 | STS | 790/790 | 82–85 | WTR | | 6,12 |
| | SUBTOTAL. NON-NASA | SCOUT | 3 | 2 | 2 | 1 | | | | | | | | | 8 | | | | | | | | |
| | SUBTOTAL, NON-NASA | AIF,NOS,NOM | 2 | 3 | 2 | 2 | 4 | 4 | 6 | 4 | 4 | 4 | 7 | 5 | 46 | | | | | | | | |
| | TOTAL | SCOUT | 5 | 3 | 4 | 1 | | 1 | | 1 | | 1 | | 1 | 17 | | | | | | | | |
| | TOTAL | AUTOMATED SPACECRAFT | 2 | 4 | 4 | 6 | 8 | 7 | 10 | 7 | 8 | 8 | 11 | 8 | 83 | | | | | | | | |
| | TOTAL | LABORATORIES & OBSERVATORIES | | | 1 | 2 | 4 | 3 | 3 | 3 | 4 | 3 | 2 | 4 | 29 | | | | | | | | |

* Revised data (Ref., BMI-NLVP-IM-77-5)

- Estimated follow-on activities during the mid-to-late 1980's (e.g., #13 Solar Mesosphere Explorer and #19 Magsat Follow-On)(Reference 5).

The small to intermediate size automated spacecraft include science explorers and application explorers (items 1-5 and 19-26 in Table 2-I). They are expected to be launched at rates of one and two per year (References 4 and 5). The Upper Atmosphere Research Satellite (UARS) (items 15 and 16 in Table 2-I) is being considered as a possible new start in the early 1980's and will feature pairs of cooperating spacecraft launched every three-to-four years to conduct soundings of the upper atmosphere (Reference 3). Another possible new start, Origin of Particles in the Earth Neighborhood (OPEN), will use spacecraft launched into highly elliptical orbits to study the composition of plasma in the Earth mesosphere. It is scheduled to repeat the OPEN experiments every three to four years (Reference 5). A Solar Maximum Follow-On mission (item 14 in Table 2-I) is included in the low energy payload model. Although the first Solar Maximum mission spacecraft (to be launched in 1979 by Delta) is to use the Multimission Modular Spacecraft (MMS) bus and propulsion system, the follow-on spacecraft are assumed to be viable candidates for this low energy payload model. A similar rationale is considered applicable to the cases of Landsat D/E follow-on (item 28) and TIROS O/P (item 29).

The intermediate to large laboratories and observatories presented in the NASA portion of the low energy payload model represent payloads which, for the most part, could be launched to their destination orbits by the Shuttle alone. Nevertheless, they are included in this low energy payload model as possible candidates for further study. Only the astrophysics observatories (items 6-11 in Table 2-I) are identified specifically. Other payloads are identified generically (items 18, 31, and 32) based on data presented in References 1 through 3.

2.1.1.2 Non-NASA Payloads - The non-NASA payloads of the model include 10 mission line items and a total of 53 payloads of which 7 are Scout payloads and 46 are small to intermediate size automated spacecraft. A brief review of non-NASA user requirements indicates that relatively few missions fit the low energy mission category. Most non-NASA payloads will be placed in

geosynchronous orbit and are not part of this low energy payload model. In addition, Battelle did not include Japanese or European small spacecraft in the model since the Japanese and the Europeans are introducing launch vehicles which are expected to launch most or all of their own spacecraft. The payloads that are included are predominantly meteorological and observational spacecraft placed in polar and Sun synchronous orbits.

U.S. Government/civil activities are represented by a projected Operational Seasat program, a NOAA (ITOS) follow-on program and an Earth Resources Satellite (operational Landsat) program. A total of 17 payloads are projected for these three programs based on the "low-level model" of Reference 6.

The DoD programs include a follow-on series of Transits for the U.S. Navy and those representative U.S. Air Force programs (items 36, 37 and 38 in Table 2-I). The Transits are expected to be launched by Scout. After the four launches indicated in Table 2-I are completed, it is expected that the Transit program will be terminated and its function will be served by the U.S. Air Force Global Positioning System (GPS) Navstar satellites. These satellites will be outside the range of this low energy payload model. The USAF programs considered appropriate for this model are the follow-on Space Test Program (item 37) and the USAF meteorological satellite program (item 38). Both programs are estimated to continue through the decade of the 1980's at a rate of one launch per year for each program. At the present, the USAF meteorological satellite program is served by the Block 5D spacecraft with two solid-propellant upper stage motors (Reference 10).

The foreign payloads in the low energy payload model include two San Marco Scout launches. Three Canadian scientific spacecraft are projected for launching in the early-to-mid 1980's using either Scout or the STS. The Canadian scientific program is expected to continue with two Shuttle payloads in the late 1980's. In addition, the Canadians are planning an All-Weather Microwave satellite that might be operated in conjunction with the Operational Seasat program (NOAA) to provide an operational global microwave observation system.

2.1.1.3 Payload Mass Estimates - Mass estimates for the low energy payloads are given in Table 2-II, categorized by major subsystem to indicate how

TABLE 2-II PAYLOAD MASS ESTIMATES(a)

| | Payload | Mass of Indicated Item, kg | | | |
|---|---|---|---|---|---|
| | | Instruments | Structure | Other Subsystems(b) | Total |
| 1. | Cosmic Background Explorer | 590(4) | 165*(4) | 200 | 955* |
| 2. | Extreme UV Explorer | 75*(4) | 50*(4) | 115* | 240* |
| 3-5. | Astrophysics Explorers(3) Note 1 | 100-500 | 100-250 | 100-250 | 300-1000 |
| 6-7. | Gamma Ray Astronomy Obs., Cosmic Ray Obs.(7) | 6155 | 500 | 1515 | 8170 |
| 8. | X-Ray Observatory(7) | 8815 | 500 | 1515 | 10830 |
| 9. | 1.2-m X-Ray Telescope(7) | 4226 | 500 | 1515 | 6240 |
| 10-11. | LAMAR, Meter-Class UV Telescope | 6305 | 500 | 1515 | 8320 |
| 12. | Active Magnetospheric Particle Tracer (AMPTE)(8) | -- | -- | -- | 66 |
| 13. | Solar Mesosphere Explorer(8) | -- | -- | -- | 150 |
| 14. | Solar Maximum F/O(7) | 570 | 379 | 411 | 1360 |
| 15-16. | Upper Atmospheric Research Satellite (UARS)(7) | 70 | 100 | 130 | 300 |
| 17. | Origin of Particles in Earth Neighborhood (OPEN)(7) | 60 | 100 | 110 | 270 |
| 18. | Small Observatory Class(3) | -- | -- | -- | 1500-2000 |
| 19. | Magsat F/O(8) | -- | -- | -- | 170 |
| 20-21. | STEREOSAT | 35(4) | 50 | 115 | 200 |

TABLE 2-II PAYLOAD MASS ESTIMATES
(Continued)

| | Payload | Mass of Indicated Item, kg | | | |
|---|---|---|---|---|---|
| | | Instruments | Structure | Other Subsystems[b] | Total |
| 22. | Earth Radiation Budget Satellite (ERBS) | 25[4] | 50 | 125 | 200 |
| 23-26. | Applications Explorers[3] | -- | -- | -- | 200-1000 |
| 27. | SEASAT B[7] | 1324* | 259* | 1281* | 2864* |
| 28. | LANDSAT D/E F/O[7] | 483 | 435 | 694 | 1612 |
| 29. | TIROS O/P[7] | 272 | 531 | 630 | 1430 |
| 30. | Coastal Zone Monitor | 500 | 250[4] | 250 | 1000 |
| 31. | Intermediate Class Observatories[3] | -- | -- | -- | 4000-5000 |
| 32. | Large Observatories[3] | -- | -- | -- | 8000-10000 |

(a) Superscript numbers in the table are references
(b) Estimates include allocations for attitude control ~10 to 20 kg) but not for orbit adjust propulsion. In those cases where orbit adjust propulsion was included in the original estimate (e.g., GRAO, CRO, XRO, LANDSAT, TIROS, SMM), the allocation, generally 180 kg, was deducted.

* Revised data from "SEASAT-B and Operational SEASAT Configurations" Battelle Columbus Laboratories, BMI-NLVP-77-130, November 23, 1977

NOTE:
1. Numbers in parenthesis refer to references on page 128 of this volume.

the estimates were derived. These subsystems included avionics, instrumentation, structure, electrical, thermal, attitude control, etc. The mass estimates do not include allocations for orbit adjust propulsion (raising and lowering orbit altitude and stationkeeping).

For many small payloads, the only item that has been defined and documented is the instrument or experiment that is the heart of the payload (Reference 13). For explorer-class spacecraft, these items may weigh as little as 25 to 100 kg. The remainder of the payload may be projected as either a Scout-compatible spacecraft or a Shuttle-compatible spacecraft. For Scout-compatible payloads, the allocation for structure is estimated to be about 50 kg, and for other subsystems, the allocation is about 100 kg or less. For Shuttle-compatible payloads, GSFC has proposed a basic truss structure designed to span the Shuttle cargo bay that would weigh about 250 kg and would provide ample space and strength for mounting one or more instruments and their supporting subsystems (Reference 4).

For intermediate to large spacecraft such as Gamma Ray Astronomy Observatory, Landsat D/E and TIROS O/P, the mass estimates in Table 2-II are based on the existing Multimission Modular Spacecraft designs (Reference 7), with the mass allocations for orbit adjust propulsion deducted. This procedure leaves the MMS bus and the electrical thermal and the guidance and control subsystems as part of the remaining spacecraft mass.

Figure 2.1 is a mass-energy map for the low energy missions. The uppermost boundary of the Low Energy regime is the performance curve for a SSUS-D. For the payloads shown here it is assumed that:

- the Shuttle delivers payloads to circular parking orbits at 296 km (160 nm) altitude,
- the Shuttle establishes the orbit inclination desired by the payload between 28.5 to 104°
- orbit inclinations less than 28.5 degrees or greater than 104 degrees would require plane changes provided by an upper stage.

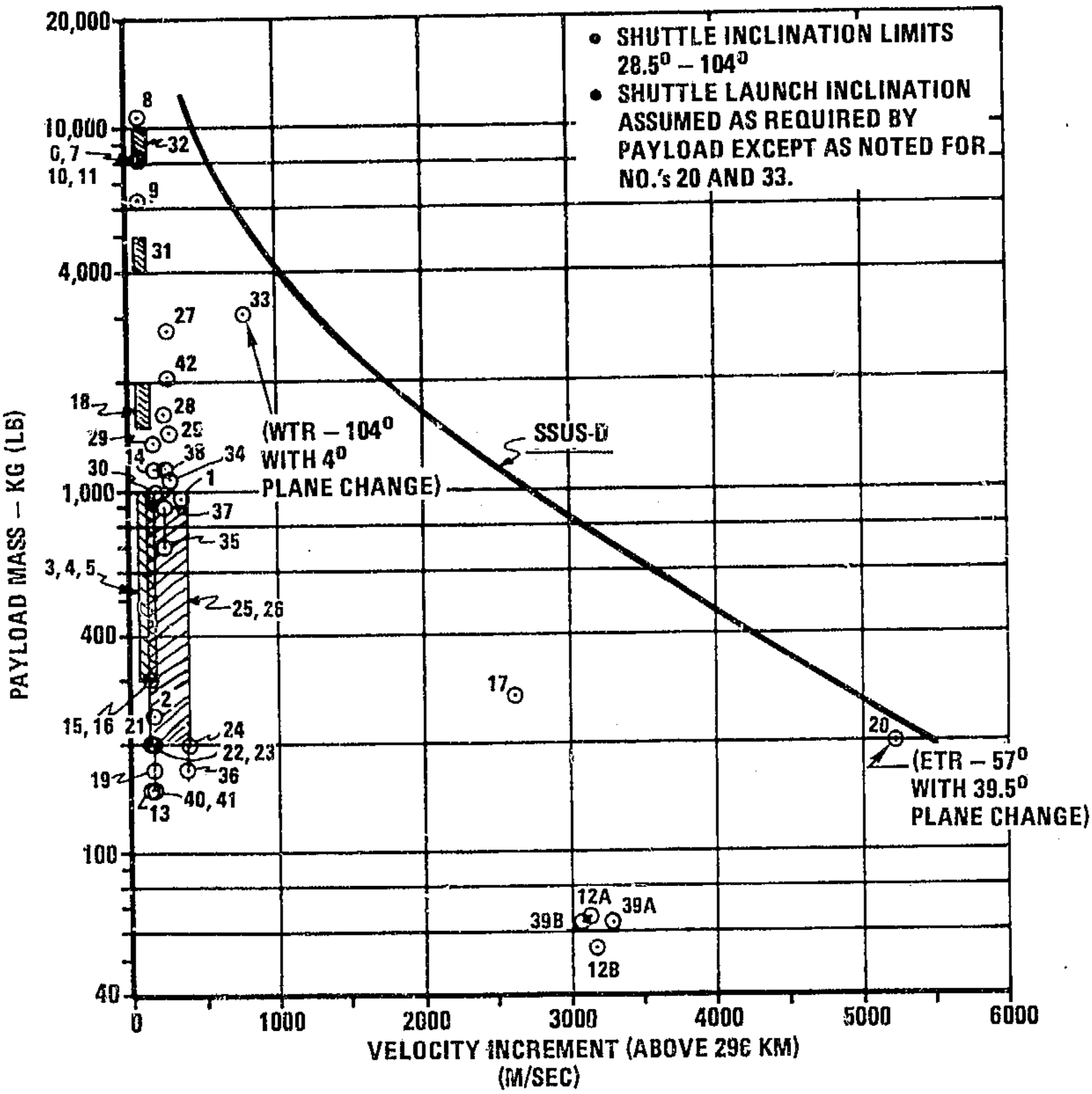



FIGURE 2.1 INITIAL LOW ENERGY PAYLOAD MODEL – MASS-ENERGY REQUIREMENTS WITHOUT SHUTTLE INCLINATION CONSTRAINT

LESS-002

Plane changes would be required for two missions. It has been proposed that the 1981 Stereosat mission (item 20 in Table 2-I ) be launched aboard an ETR Shuttle at an inclination of 57 degrees and perform a plane change of 39.5 degrees to arrive at its desired inclination of 96.5 degrees. The total velocity impulse requirement to perform the plane change and altitude change is 5254 mps. The other mission requiring a plane change is Operational Seasat (item 33 in Table 2-I ). In this case, the Shuttle parking orbit is assumed to be 104 degrees and that of the Operational Seasat is 108 degrees.

Payloads are represented by numbered circles and by shaded regions. The numbers correspond to the mission line item numbers in Tables 2-I and 2-II. Three distinct groupings of payloads are evident on the map. The payload grouping in the lower left corner consists of Scout-class payloads. The payloads in the upper left corner are the large free-flyer laboratories and observatories. The remaining are NASA, Civil, Department of Defense and foreign payloads. They include Explorer series, small free-flyers, small observatories, and some medium-weight, highly-elliptical satellites requiring intermediate velocity increment.

This payload-mission model, developed by Battelle in Reference 14, was provided by the COR in Reference 15.

### 2.1.2 Model Review

A Vought review was conducted of the latest available NASA, DoD, Civil and Scout payload/mission data (Reference 14) and the results of this review compared against the IES payload-mission model. Based on this review Vought recommended to Battelle that the following changes be made to the model:

- Mission number 9 (in Table 2-I), the 1.2 meter X-ray Telescope, has only one launch which is scheduled in 1985. The payload weight is 10,000 kg, and the length is 13.5 meters.
- The Stereosat, mission number 20, payload weight is not firmly established and could be less than 200 kg. It could be considered as a potential payload for a Scout launch from WTR.
- Coastal Zone Monitor, mission number 30, could be launched from ETR.

- USAF Meteorological Satellite, mission number 38, launches prior to Shuttle operations from WTR could be launched with an expendable launch vehicle. Prior to 1983 it should not be considered a LES payload.
- The length and diameter of the Solar Maximum Mission Follow-On, mission number 14, are reversed in Table 2-I.
- The orbits for the two San Marco DL, mission number 39, were defined to be the following:

  39A - Apogee, 800 km
  Perigee, 200 km
  Inclination, 2.9 degree

  39B - Apogee, 27400 km
  Perigee, 420 km
  Inclination, 2.9 degree

As a result of the above recommended changes to the payload mission model, a reduction of missions and payloads were made. The change was from (48/129) to (46/125). The payload mission model with the changes noted here was used as the basis for the selection of reference missions, representative of the model, which were then used in this Volume, paragraph 3.0, as the basis for the development and evaluation of propulsion approaches for LES payload delivery. A revision to the mission model was received in April of 1978. This revision, which is discussed in Volume III, paragraph 4.1, was used in all work subsequent to Task 3, Volume III.

### 2.1.3 Mass/Energy Relationship of Payload Mission Model

The standard Shuttle mission destinations, defined in Reference 16, are:

| LAUNCH SITE | CIRCULAR ORBIT ALTITUDE | INCLINATION |
|---|---|---|
| ETR | 296 km (160 nm) | 28.5°<br>56.0° |
| WTR | 296 km (160 nm) | 90.0°<br>104.0° |

In addition, instructions received with the LES Payload Mission Model (Reference 15) state that Shuttle launch and landing at WTR should be assumed

for payloads launched in 1983 and beyond.

Based on the four Shuttle inclinations specified and the initial operational date from WTR, the payload weight/energy requirements were recomputed to include the velocity increment required for transfer from the Shuttle orbit altitude (296 Km) and available inclination to the payload destination orbit altitude and inclination. Inclination change is held to the minimum by assuming that the orbit inclination delivered by the Shuttle is the one closest to the payload destination orbit inclination. The distribution of velocity increment required by the payloads of the model is shown in Figure 2.2. Here the payloads fall into five or perhaps six distinct groupings. Payloads in the upper left corner are the large free-flyer laboratories and observatories. The Scout-class payloads now fall into two groups: (1) the very low mass and velocity increment near 3500 meters per second for the near equatorial orbits when launched from a 28.5° Shuttle orbit, and (2) the heavier payloads with polar and sun synchronous inclination requirements when launched from ETR prior to 1983. There also are some Scout payloads in the low mass, low energy region. The remaining payloads, with velocity requirements less than 1000 meters per second, tend to divide into two weight regions - one near 300 kg and the other concentrated near 1000 kg. There is, however, a reasonable scatter of payloads in the last region that extends to weights near 3000 kg, and require plane changes between four and nine degrees. The upper boundary of the low energy payload/mission regime is also shown.

## 2.2 REFERENCE MISSIONS

The requirements and characteristics of the LES model payloads and their missions are quite diverse. They cover a broad spectrum of destination orbit altitudes and inclinations; their launch schedule spans the period of Shuttle operational initiation from both ETR and WTR and beyond; and their mass properties, geometry, acceleration, stabilization, and accuracy characteristics and requirements cover a broad spectrum. Mission and budget planning data recently available and refinements of plans for introducing the Shuttle tend to help firm up projections of mission activities and payloads through the early 1980's. However, after that time projections

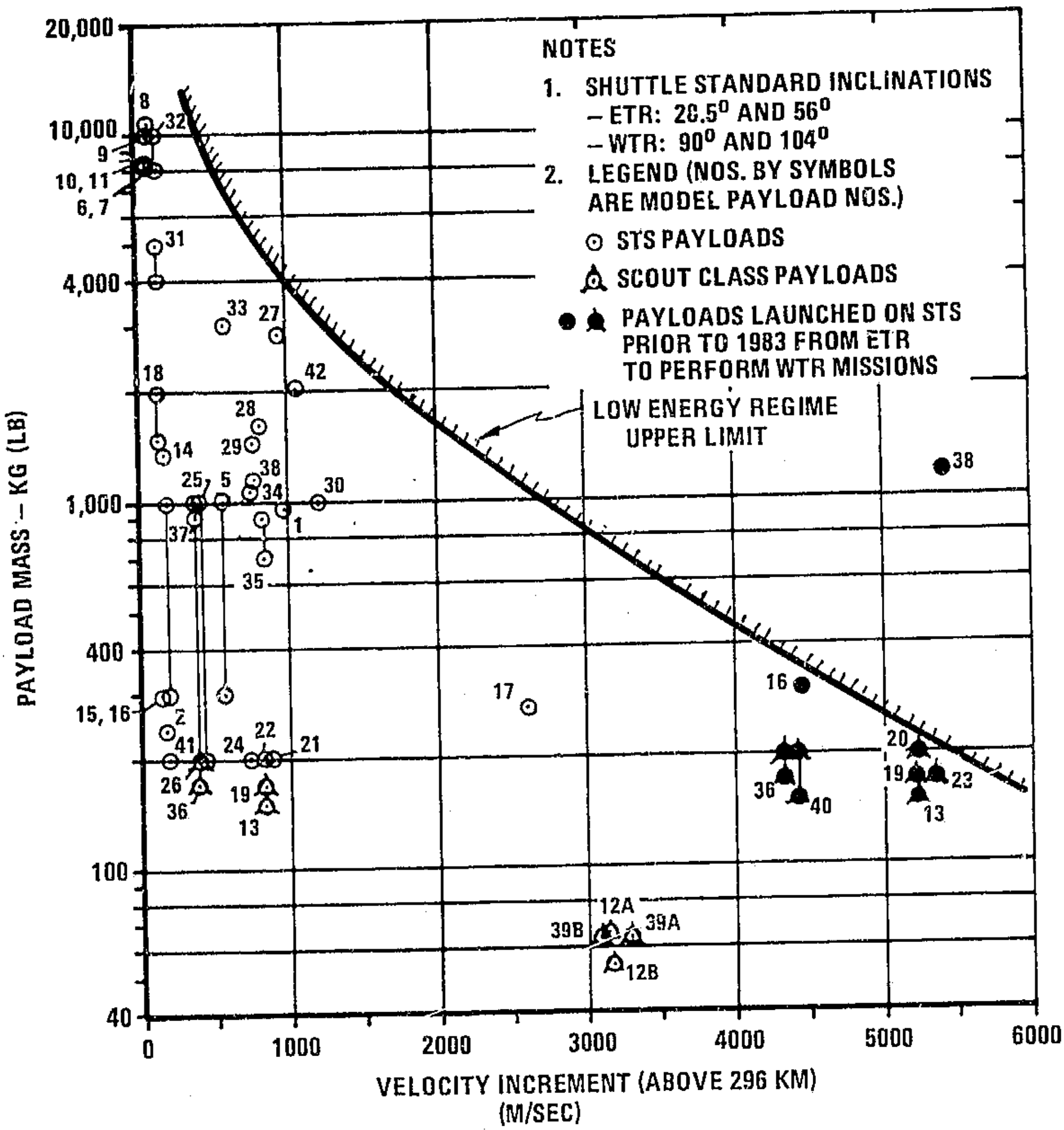



FIGURE 2.2 INITIAL LOW ENERGY PAYLOAD MODEL – MASS-ENERGY REQUIREMENTS WITH SHUTTLE INCLINATION CONSTRAINT



LESS-004

are less firm due to uncertainties in technical, schedule, and budget plans including the impact of the introduction of the Shuttle. Consequently, not only are the requirements and characteristics of the LES model payloads diverse but their specific characteristics, schedules and budgets are not firmly defined. This diversity in requirements and characteristics, the lack of firm definition and the large number of missions and payloads (46/125) make it difficult to address each mission or payload in the course of a feasibility study to assess cost effectiveness of the many existing, planned or new propulsion approaches for delivery of these payloads to their destination orbits. Consequently, a set of six reference missions were selected to represent the significant areas of the low energy regime for the initial screening of the candidate delivery approaches. These points were selected to assure that all of the payloads of the model were accommodated by at least one reference mission.

### 2.2.1 Selection Rationale

The rationale used in the selection of reference missions assured that the definition of the missions would be compatible with the logical groupings of payloads and missions of the LES study model as shown in Figure 2.2. This grouping reflects the Shuttle standard orbit inclinations specified in Reference 16 and the currently defined schedule for initiation of operations from both ETR and WTR (Reference 15). The specific factors considered in the selection of the six reference missions which represent the groupings of the model payloads are as follows:

- Representative payload definition in terms of weight and energy required.
- Launch site definition and orbit plane change required of the upper stage system from the standard Orbiter inclinations.
- Potential launch modes in terms of Orbiter/OMS capability, existing/planned upper stages, new low energy stages, new low energy stage approaches, and expendable launch vehicles.

- Orbiter cargo bay installation potential as reflected in horizontal, vertical, and/or side-by-side installation oriented toward minimizing the Shuttle user charge for the upper stage and deployment system.

The implementation of this rationale and the considerations for each of the reference missions are shown in Table 2-III. A secondary goal of the selection was to define existing or planned upper stages or expendable launch vehicles with capabilities consistent with the reference mission requirements.

### 2.2.2 Selected Reference Missions

The relationship of the selected reference missions weights and velocity increments (above 296 km) to the requirements of the missions and payloads of the LES model is shown in Figure 2.3. Each reference mission was selected to provide a weight-energy relationship which assures coverage of the related payloads which are enclosed in dashed lines. The reference missions relationship to the LES mission model is shown in Table 2-IV in terms of payload type, mission model payload codes, mission model numbers and quantity of payloads, number of missions and payloads, payload weight, and velocity increment above the Orbiter altitude of 296 km. Also shown are the resulting destination orbit altitudes and inclinations for each reference mission as well as the Shuttle orbit altitude, inclination and launch site.

- Reference Mission A, at 10,000 kg, is representative of the large and medium size observatories and laboratories to be placed in near 500 km orbits at inclinations of 28.5 degrees from ETR. It reflects the requirements of 8 missions and 17 payloads of the model.

## TABLE 2-III REFERENCE MISSION SELECTION RATIONALE

| REFERENCE MISSION POINT | REPRESENTATIVE PAYLOAD | ORBIT INCLINATION FACTORS | | POTENTIAL LAUNCH MODE | CARGO BAY INSTALLATION POTENTIAL |
|---|---|---|---|---|---|
| | | LAUNCH SITE | INCLINATION CHANGE~DEG | | |
| A | • HIGH WEIGHT<br>• LARGE SIZE<br>• LOW ENERGY | ETR | 0 | • ORBITER/OMS<br>• STAR 48/AKM (SSUS-D)<br>• MID SIZE NEW LES | • SINGLE LARGE PAYLOAD INSTALLED HORIZONTALLY |
| B | • MEDIUM HIGH WEIGHT<br>• MEDIUM HIGH SIZE<br>• MEDIUM ENERGY | WTR | 4-9 | • TELEOPERATOR WITH TANKS<br>• STAR 48/AKM (SSUS-D)<br>• LARGE NEW LES | • MEDIUM HIGH SIZE PAYLOAD INSTALLED HORIZONTALLY |
| C | • MEDIUM WEIGHT<br>• MEDIUM SIZE<br>• LOW ENERGY | ETR | 1 | • ORBITER/OMS<br>• MMS + PM-1T<br>• TELEOPERATOR WITH TANKS<br>• SMALL NEW LES | • MEDIUM SIZE PAYLOAD INSTALLED HORIZONTALLY |
| D | • LOW WEIGHT<br>• SMALL SIZE<br>• LOW ENERGY | WTR | 4-9 | • ORBITER/OMS<br>• MMS + PM-1T<br>• TELEOPERATOR WITH TANKS<br>• SMALL NEW LES<br>• SCOUT | • INNOVATIVE PACKAGING<br>• HORIZONTAL OR VERTICAL<br>• OVER AND UNDER<br>• OVER THE SPACELAB |
| E | • LOW, WEIGHT<br>• SMALL SIZE<br>• MEDIUM HIGH ENERGY | ETR | 25.6 | • STAR 48/AKM (SSUS-D)<br>• LARGE NEW LES<br>• SCOUT FROM SAN MARCO | • SAME AS D |
| F | • LOW WEIGHT<br>• SMALL SIZE<br>• HIGH ENERGY | ETR | 41.5 | • STAR 48/AKM (SSUS-D)<br>• LARGE NEW LES<br>• SCOUT FROM WTR | • SAME AS D |

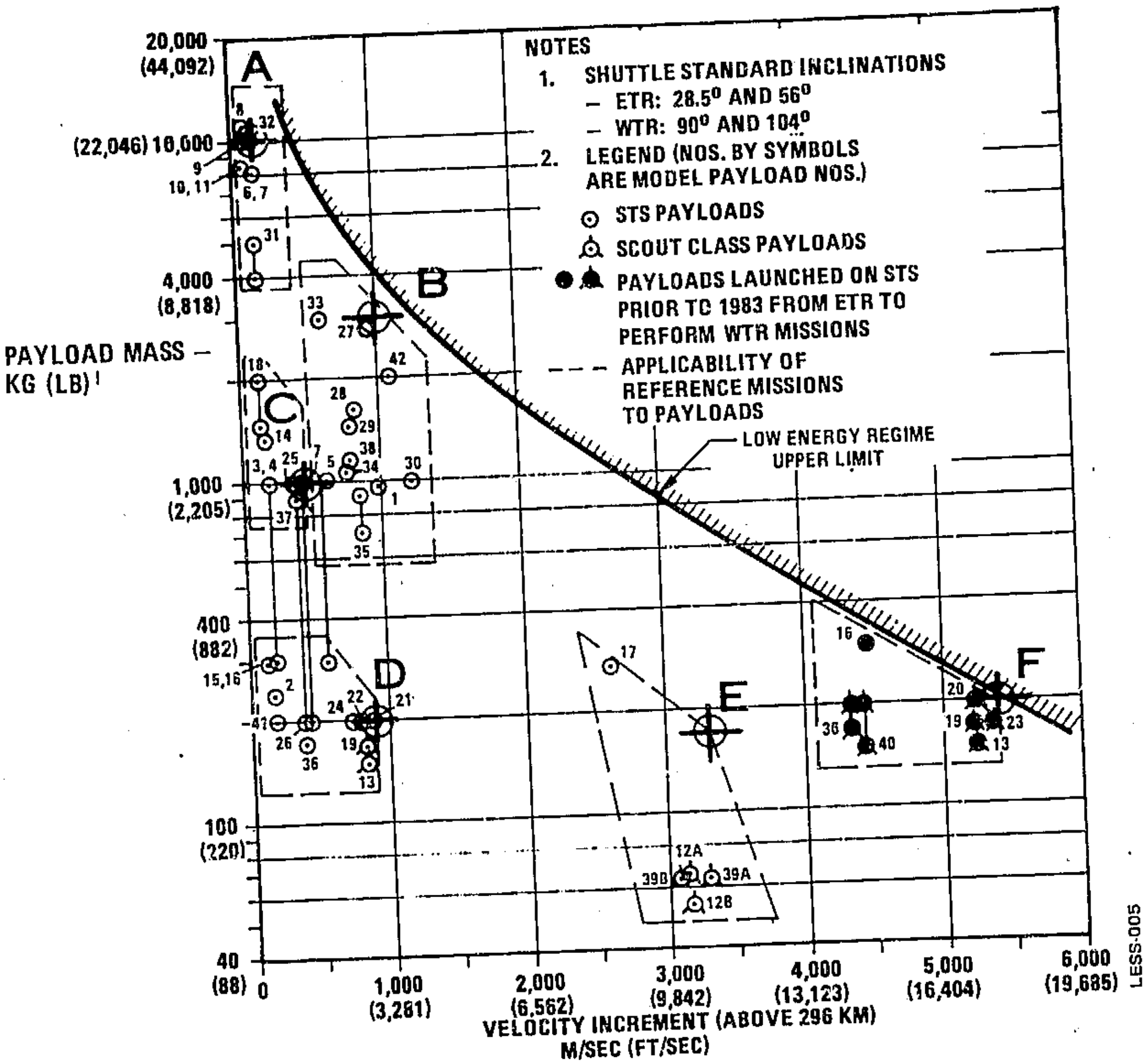



FIGURE 2.3 RELATIONSHIP OF MASS AND ENERGY OF REFERENCE MISSIONS TO MODEL PAYLOAD/MISSION REQUIREMENTS

## TABLE 2-IV REFERENCE MISSIONS RELATIONSHIP TO LES MISSION MODEL

| MISSION | TYPE PAYLOAD | LES MISSION MODEL | | | | PAYLOAD WEIGHT KG (LB) | VELOCITY INCREMENT FROM 296 KM SHUTTLE ORBIT MPS (FPS) | DESITNATION ORBIT | | | SHUTTLE ORBIT (ALT. = 296 KM) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PAYLOAD CODES | MODEL MISSION NUMBERS (QUANTITY OF PAYLOADS) | NO. OF MISSIONS | NO. OF PAYLOADS | | | ALTITUDE KM (NMI) | | INCL. DEG. | INCL. DEG. | LAUNCH SITE |
| | | | | | | | | PERIGEE | APOGEE | | | |
| A | LARGE AND MEDIUM SIZE OBSERVATORY | SIO, SLO, STI, STL | 6, 7, 8, 9, 10, 11, 31, 32 (2, 2, 2, 1, 1 , 1 , 4 , 4 ) | 8 | 17 | 10,000 (22,050) | 120 (394) | 500 (270) | 500 (270) | 28.5 | 28.5 | ETR |
| B | MEDIUM SIZE FREE FLYER | SES, SSO, AIF, NOM | 1, 5, 27, 28, 29, 30, 33 (2, 1, 1 , 2 , 2 , 2 , 6 ) 34, 35, 38, 42 (3 , 8 , 9 , 2 ) | 11 | 38 | 3,000 (6,615) | 1,000 (3,281) | 1,000 (540) | 1,000 (540) | 97 | 90 | WTR |
| C | SMALL SIZE FREE FLYER | SES, SSO, SSF, LSO, ASF | 3, 4, 14, 18, 25, 37 (2, 1, 3 , 11, 3 , 12) | 6 | 32 | 1,000 (2,205) | 400 (1,312) | 1,000 (540) | 1,000 (540) | 57 | 56 | ETR |
| D | EXPLORERS & SCOUT CLASS FROM WTR | SES, SSO, SSF, NOS, ASF, SCOUT CLASS | 2, 13, 15, 16, 19, 21 (1, 2 , 3 , 2 , 2 , 1 ) 22, 24, 26, 36, 41 (2 , 1 , 4 , 1 , 3 ) | 11 | 22 | 200 (441) | 900 (2,953) | 577 (312) | 577 (312) | 96.5 | 90 | WTR |
| E | EXPLORERS & SCOUT CLASS INTO EQUATORIAL ORBIT FROM ETR | SSF, SCOUT CLASS | 12A, 12B, 17, 39A, 39B (1 , 1 , 2 , 1 , 1 ) | 3 | 6 | 170 (375) | 3,300 (10,827) | 1,111 (600) | 1,111 (600) | 2.9 | 28.5 | ETR |
| F | EXPLORERS & SCOUT CLASS INTO NEAR POLAR ORBIT FROM ETR PRIOR TO 1983 | SSF, ASF, SCOUT CLASS | 13, 16, 19, 20, 23, 36, 40 (1 , 1 , 1 , 1 , 1 , 3 , 2 ) | 7 | 10 | 200 (441) | 5,400 (17,717) | 1,000 (540) | 1,000 (540) | 97.5 | 56 | ETR |

- Reference Mission B, at 3000 kg, represents medium size free-flyers into polar and sun synchronous orbits of up to 1000 km altitude when launched from WTR. There are 11 missions and 38 payloads in this model category.
- Reference Mission C, 1000 kg, reflects the requirements for small size free-flyers launched from ETR in orbits of 1000 km altitude and inclinations up to 57 degrees. Six missions and 32 payloads of the model are represented.
- Reference Mission D, at 200 kg, is representative of Explorer and Scout class satellites launched from WTR into sun synchronous orbits to 577 km altitude from 90° inclination Shuttle orbits from WTR. There are 11 missions and 22 payloads of the model represented here.
- Reference Mission E, 170 kg, represents Explorer and Scout class payloads destined for essentially equatorial orbits at altitudes near 1111 km when delivered from the Orbiter in a 28.5° orbit. Launch is from ETR. There are 3 missions and 6 payloads in this class.
- Reference Mission F, at 200 kg, is representative of Explorer and Scout class payloads destined for 1000 km polar or sun synchronous orbits prior to the 1983 operational date of the Shuttle from WTR. The velocity increment is that required to deliver these payloads from the Orbiter which is in a 296 km altitude, 56° inclination orbit after launch from ETR. Seven missions and 10 payloads are in this group.

For each of the selected reference missions there is at least one existing/planned upper stage or adaptation of these that will satisfy mission requirements. For half of the missions there are three approaches for payload

delivery. Preliminary investigation indicates that the payload geometry of half of the missions offer opportunities for innovative packaging arrangements in the Orbiter cargo bay.

2.2.3 Existing/Planned Upper Stage Performance Capabilities

The capability of existing/planned upper stages to meet the payload weight-velocity increment requirements of the reference missions is shown in Figure 2.4. This relationship of existing/planned propulsion approaches or their adaptations to specific reference missions is shown below.

| REFERENCE MISSION | EXISTING/PLANNED APPROACHES OR ADAPTATIONS |
|---|---|
| A | • Orbiter + 1 OMS Kit.<br>• SUSS-D + AKM |
| B | • SUSS-D + AKM |
| C | • Orbiter + 3 OMS Kits<br>• MMS / PM-II<br>• Teleoperator / 2 Tanks |
| D | • Teleoperator / 4 Tanks<br>• Scout |
| E | • SUSS-D + AKM<br>• Scout from San Marco |
| F | • SUSS-D + AKM<br>• Scout from WTR |

A very inefficient use of a SSUS-D (also defined as Spinning Star 48 in part of the report) with an apogee kick motor (AKM) will also handle reference Missions C and D.

## 2.3 PAYLOAD CHARACTERISTICS AND REQUIREMENTS

In the development of the characteristics and requirements for the six reference payload missions the following procedure was used. The payload identified in the LES model (References 14 and 15) were reviewed against those identified in the STS Payload Model Summary (Reference 1), the STS Traffic Manifest (Reference 2), the NASA Payload Model Generic Payload Descriptions (Reference 7) to establish, where possible, more detail descriptions of the characteristics and requirements of the payloads. Data for most of the NASA payloads were available from these references, but there were

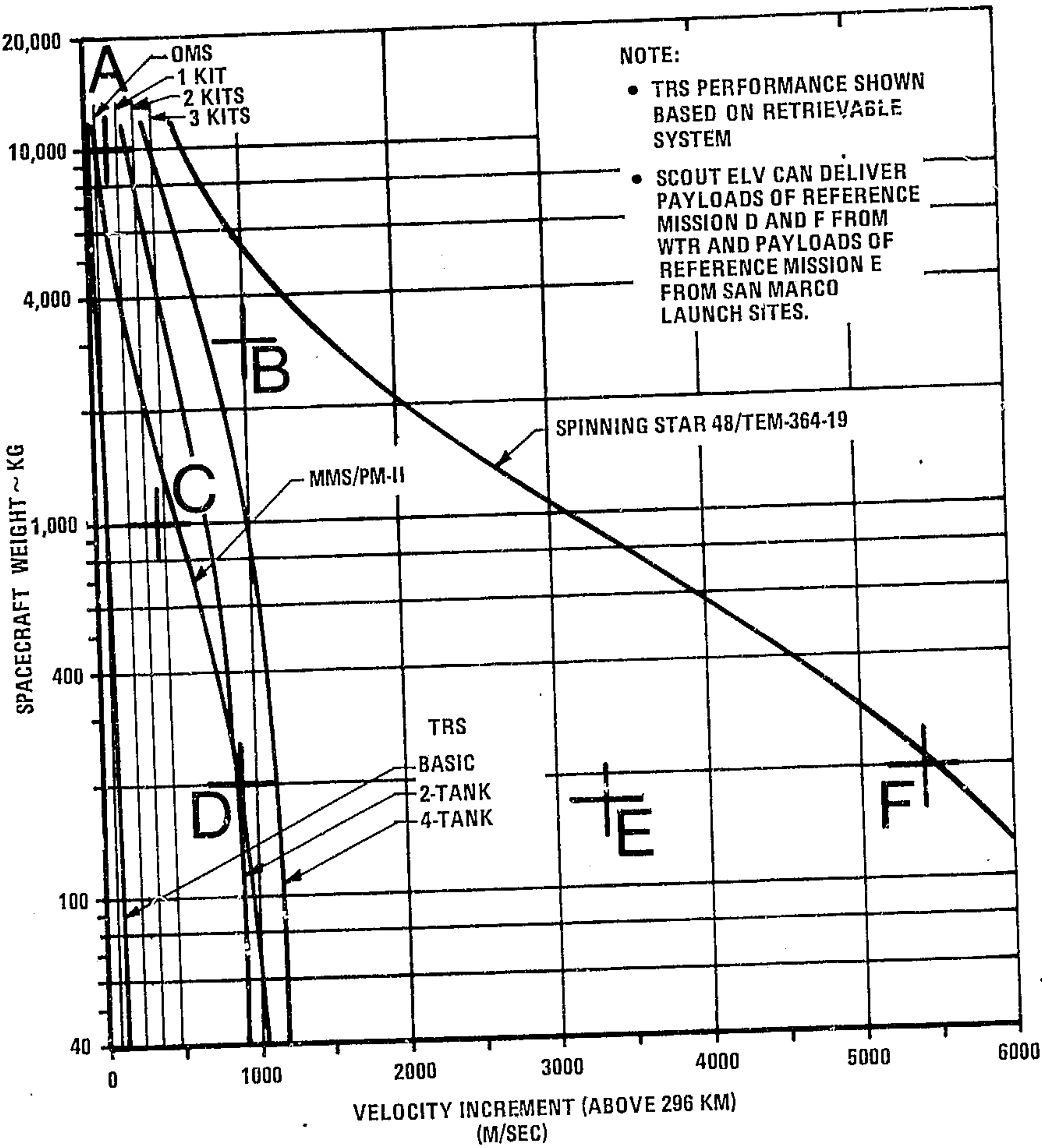



FIGURE 2.4 PERFORMANCE CAPABILITY OF EXISTING/PLANNED SYSTEMS

less significant data available for Civil, DoD and foreign payloads. Scout payload data descriptions were available. Approximately 28% of the LES model payloads had Level B data (Reference 3). Level B data (Reference 7) provides engineering descriptions of payloads identified by the payload program offices and Shuttle Payload Planning working groups which are projected for the early Space Shuttle era. The characteristics and requirements of the payloads were grouped according to their relationship to the selected reference payload/ missions. Reference payload characteristics and requirements were chosen which either essentially encompassed, or where necessary because of the nature of the parameter, were representative averages of those of the payloads of the model. A selection of characteristics or requirements which were the largest and most stringent of all of the parameters would have produced reference payloads with such extremes that they would not have truly represented the payloads of the model.

2.3.1 Payload Data Review

The almost 50 different payloads of the LES model which include a broad spectrum of payloads from research through application to operational satellites for NASA, Civil, DoD and foreign users and developed to be launched by expendable launch vehicles as well as the Shuttle have a broad and diverse combination of characteristics and requirements. However, when these payloads are grouped as they were earlier in terms of spacecraft weight and energy requirements, there results some degree of ordering of the other payload parameters. Reference mission payload weights and mission requirements in terms of velocity increment, and destination orbit description as well as Shuttle launch site and orbit description were reviewed earlier when reference missions were selected. However, a review of these and other characteristics and requirements of the payloads of the model follows.

- Payload Mass - Of those missions represented by Reference Mission A only one, scheduled in the 1985-1989 time frame, has a mass greater than the 10,000 kg. selected (see Table 2-V). Only Operational Seasats, to be launched after 1985, are 96 kg heavier than the selected 3000 kg mass selected for Reference Mission B and these have an energy requirement below the level selected. About half of the missions of Reference Mission C have mass greater than 1000 kg selected but their energy requirements are much lower than

that selected. For Reference Missions D, E and F each have a few payloads whose mass is greater than selected but here again energy requirements are below the levels selected.

- Payload Dimensions - With exception of Reference Missions A and D all selected lengths and diameters are the same as the maximums shown in Table 2-V. For Reference Mission A the X-Ray Observatory (#8) has a length of 16 meters (2.5 m greater than selected), which does not leave length in the Orbiter cargo bay for one OMS kit. Since this payload is considered a candidate for a dedicated launch by the Shuttle with an OMS kit, thus to develop a reasonable candidate for a LES stage the length for Reference A payload was selected as 13.5 m. For Reference Mission D only two missions (total of 5 payloads) have diameters greater than the 1.4 m selected. Four of these payloads are scheduled after 1985 and may not be well defined.
- Orbit Altitude - With the exception of Reference Missions D and E the selected circular orbit altitudes are equivalent to the maximum altitudes shown in Table 2-V. Several of the payloads grouped under Reference Mission D have higher altitudes but the 577 km circular orbit is a reasonable representation of the eleven missions and 22 payloads. In the case of Reference Mission E all of the orbits are highly elliptical and the 1111 km circular orbit selected is representative of the energy required.
- Orbit Inclination - All of the Reference Mission A model payloads require the 28.5° orbit selected. For Reference Mission B the payload orbits vary from 65° to 108°; the maximum plane change required from the selected Shuttle inclinations is only 9°. The inclinations required by the payloads of Reference Mission C are 28.5°, 56° and 57°; maximum plane change is 1°. The missions grouped under

TABLE 2-V SPECTRUM OF LES MODEL PAYLOADS MASS, DIMENSIONS AND DESTINATION ORBITS

| REFERENCE MISSION | NUMBER OF MODEL MISSIONS | NUMBER OF MODEL PAYLOADS | PAYLOAD MASS ~ KG (LB) MIN. | PAYLOAD MASS ~ KG (LB) MAX. | LENGTH ~ M (FT) MIN. | LENGTH ~ M (FT) MAX. | DIAMETER ~ M (FT) MIN. | DIAMETER ~ M (FT) MAX. | ORBIT ALTITUDE~KM (NM) MIN. | ORBIT ALTITUDE~KM (NM) MAX. | ORBIT INCL. ~DEG. MIN. | ORBIT INCL. ~DEG. MAX. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 8 | 17 | 4000 (8818) | 10830 (23,876) | 3 (9.84) | 16 (52.5) | 4 (13.1) | 4.5 (14.8) | 400 (216) | 500 (270) | 28.5 | 28.5 |
| B | 11 | 38 | 300 (661) | 3093 (6819) | 1 (3.28) | 9 (29.5) | 2.2 (7.2) | 4 (13.1) | 400 (216) | 1000 (540) | 65 | 108 |
| C | 6 | 32 | 200 (972) | 2000 (9720) | 1 (3.28) | 3 (9.8) | 4 (13.1) | 4.5 (14.8) | 400 (216) | 1000 (540) | 28.5 | 57 |
| D | 11 | 22 | 150 (331) | 1000 (2205) | 1 (3.28) | 1.8 (5.9) | 0.8 (2.6) | 4 (13.1) | 270 (146) | 1000 (540) | 28.5 | 104 |
| E | 3 | 6 | 54 (119) | 270 (595) | 1.5 (4.92) | 1.8 (5.9) | 0.8 (2.6) | 1.4 (4.6) | PERIGEE 200 (108) | APOGEE 68,860 (37,180) | 2.9 | 28.5 |
| F | 7 | 10 | 150 (331) | 300 (661) | 1.5 (4.82) | 1.8 (5.9) | 0.8 (2.6) | 1.4 (4.6) | 500 (270) | 1000 (540) | 90 | 97.5 |

Reference Mission D require launches from both ETR and WTR but the maximum plane change is only 9°. Four of the missions grouped under Reference Mission E are Scout class payloads scheduled for San Marco launches into 2.9° orbits; for launch from ETR they require 25.6° plane change. All of the missions of Reference Mission F are either polar or sun synchronous orbits required prior to 1983 when the Shuttle becomes operational from WTR. They require plane changes up to about 41°.

- C.G. and Inertias - Prior studies of a broad spectrum of payloads scheduled for launch by the Shuttle have shown that the c.g. of these payloads is generally about 40% of the length measured from the payload - upper stage interface. Mass properties of the reference mission payloads were computed based on this c.g. location, the lengths and diameters selected, and the assumption that the payloads have a homogenous radial mass distribution. The payloads are considered to be right circular cylinders.
- Acceleration - The maximum allowable longitudinal accelerations for Reference Missions A, B and C were obtained from Level B data (Reference 3). Since the payloads of Reference Missions D, E and F are primarily Scout class payloads, allowable accelerations were obtained from expected accelerations for those payloads on the Scout expendable launch vehicle.
- Spin Capability - With the exception of the payloads grouped under Reference Mission A which require a 3-axis stabilization reference system, all other payloads of the LES model can be spin stabilized during transfer to their destination orbit. For the payloads of Reference Missions B and C, which are scheduled for Shuttle launch, spin speed is about 100 rpm. Most of the payloads grouped under Reference Missions D, E and F are Scout class payloads and can be spun at 180 rpm.

- Accuracy - The orbit altitude accuracy for Reference Mission A was derived from the Level B data (Reference 3) for the large and medium sized observatories and laboratories and are quite restrictive and compatible with a 3-axis reference system required during transfer to the destination orbit. Reference Mission B payloads are polar and sun synchronous satellites most of which have on-orbit adjustment propulsion systems. These systems quite often can accommodate additional fuel to provide final orbit insertion corrections at reasonable cost instead of requiring precise delivery accuracy. Also these payloads can be spun during deliver. For these reasons, accuracy requirements compatible with the level of energy to be expended and consistent with spinning attitude control were selected. The payloads of Reference Mission C are all capable of being spun and since the available Level B data was quite restricted, a level of accuracy requirement consistent with a spinning attitude control system and the destination orbits was selected. Since the payloads of Reference Missions D, E and F are predominantly Scout class payloads, the accuracy capability of Scout has been used. Orbit inclination accuracy of all Reference Missions was obtained from relavent Level B data.
- Interface Requirements - Structural interface requirements were obtained from Level B data. The effect of functional and other physical interface characteristics on the determination of cost-effective propulsion approaches for Shuttle upper stages is manifested in development and operational costs. Since the definition of Reference missions and their payload requirements are intended to be used in the evaluation of propulsion system approaches in Task 2 and since that evaluation is to be based on approach unit costs and Shuttle user charges, these interface costs will not be used, and have not been specified.

- <u>Shuttle Bay Installation</u> - Some of the payloads of Reference Mission A are so large that they may well require support at cargo bay attach points rather than support by the upper stage. Other payloads of Reference Mission A and the payloads of all of the other Reference Missions can be supported by the upper stage and it by a cradle. The geometry of the payloads of Reference Missions A, B and C dictate that they be installed horizontally in the cargo bay. For payloads of Reference Missions A and B the lengths and diameters preclude vertical installation. The trend in the geometry of payloads of Reference Mission C over the last few years has been to increase the diameter and shorten the length to take advantage of the Shuttle user charge policy. However, the increase in diameter has produced a length charge for vertical installation that is greater than that for horizontal. Earlier shapes for these payloads had significant potential for vertical installations and the potential of reduced user charges. Payloads of Reference Missions D, E, and F all have potential for both horizontal and vertical installations in the cargo bay.

### 2.3.2 Reference Mission Payload Characteristics and Requirements

The characteristics and requirements of the payloads for each of the Reference Missions are shown in Table 2-VI. The first page of the table shows numerical and qualitative definition of the characteristics and requirements devised in the previous paragraph. Sketches of each payload with dimensions, c.g. location and structural interface definition, are shown in the second page of the table.

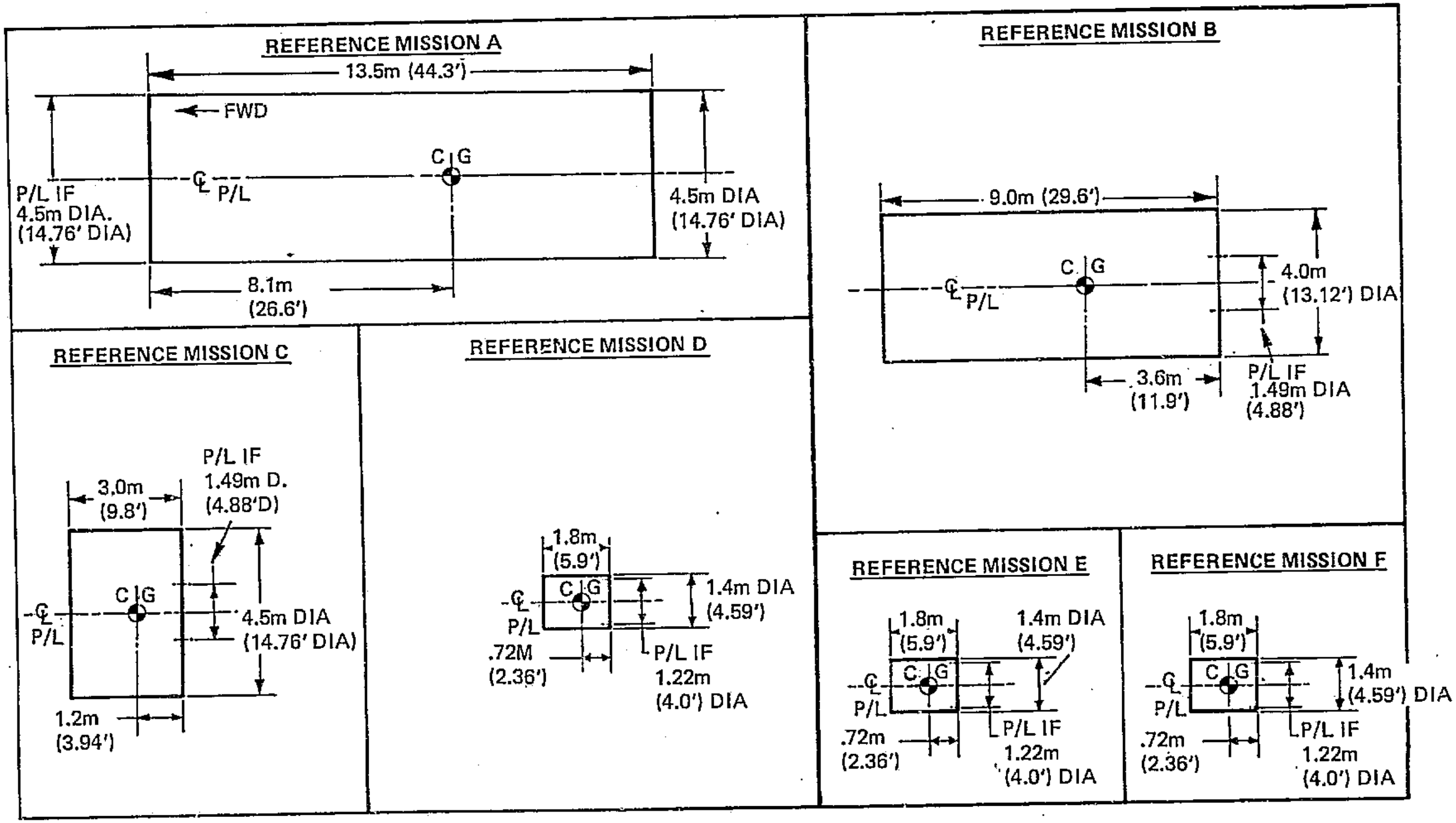
## 2.4 LAUNCH COST ENVELOPES

The basic objective of the Low Energy Stage (LES) study is to determine the most cost-effective approaches to placing automated payloads into low energy orbits. For an approach to be "cost-effective", it must, as a minimum, be cost competitive to NASA's existing/planned launch approaches. Cost and performance data for these approaches applicable to the low energy

## TABLE 2-VI REFERENCE MISSION PAYLOAD CHARACTERISTICS AND REQUIREMENTS

| MISSION | PAYLOAD | | | MASS PROPERTIES | | | LONGITUDINAL ACCELERATION MAXIMUM ALLOWABLE g's | ORBIT INSERTION ACCURACY ($3\sigma$) | | | SPIN CAPABILITY AND MAXIMUM RPM | STABILIZATION MODE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WEIGHT Kg (LB) | SIZE | | | | | | | | | | | |
| | | LENGTH M (FEET) | DIAMETER M (FEET) | $I_{ROLL}$ $Kg \cdot M^2$ ($LB \cdot FT^2$) | $I_{PITCH}$ $Kg \cdot M^2$ ($LB \cdot FT^2$) | $I_{YAW}$ $Kg \cdot M^2$ ($LB \cdot FT^2$) | | HEIGHT OF PERIGEE Km (NMI) | HEIGHT OF APOGEE Km (NMI) | INCLINATION DEGREE | | TRANSFER ORBIT | IN ORBIT |
| **A** | 10,000 (22,050) | 13.5 (44.3) | 4.5 (14.76) | 25,313 ($6.0 \times 10^5$) | 164,531 ($3.9 \times 10^6$) | 164,531 ($3.9 \times 10^6$) | 5 | ± 20 (± 10.8) | ± 20 (± 10.8) | ± 7° | NO | 3-AXIS | 3-AXIS |
| **B** | 3,000 (6,615) | 9 (29.6) | 4 (13.12) | 6,000 ($1.42 \times 10^5$) | 23,250 ($5.52 \times 10^5$) | 23,250 ($5.52 \times 10^5$) | 5 | ± 100 (± 54) | ± 100 (± 54) | ± .5° | YES 100 | SPIN | 3 AXIS |
| **C** | 1,000 (2,205) | 3 ( 9.8) | 4.5 (14.76) | 2,531 ($6.0 \times 10^4$) | 2,016 ($4.78 \times 10^4$) | 2,016 ($4.78 \times 10^4$) | 5 | ± 50 (± 27) | ± 50 (± 27) | ± 2° | YES 100 | SPIN | 3-AXIS |
| **D** | 200 (441) | 1.8 ( 5.9) | 1.4 (4.59) | 49 (1163) | 79 (1875) | 79 (1875) | 10 | ± 250 (± 135) | ± 250 (± 135) | ± 2° | YES 180 | SPIN | (42%) SPIN (38%) 3-AXIS (20%) GRAVITY GRADIENT |
| **E** | 170 (375) | 1.8 ( 5.9) | 1.4 (4.59) | 42 (997) | 67 (1590) | 67 (1590) | 10 | ± 250 (± 135) | ± 250 (± 135) | ± 1° | YES 180 | SPIN | SPIN |
| **F** | 200 (441) | 1.8 ( 5.9) | 1.4 (4.59) | 49 (1163) | 79 (1875) | 79 (1875) | 10 | ± 250 (± 135) | ± 250 (± 135) | ± 1.6° | YES 180 | SPIN | SPIN |

TABLE 2-VI REFERENCE MISSION PAYLOAD CHARACTERISTICS AND REQUIREMENTS (CONTINUED)



regime were the input for this subtask. Cost envelopes were established to represent costs of launching low energy payloads using existing approaches. Existing/planned launch approaches considered and groundrules relative to their use in the study are:

- Orbiter Maneuvering Subsystem (OMS); both integral tanks and from one to three OMS kits.
- Teleoperator Retrieval System (TRS); with both two and four monopropellant tanks units. This system is considered a reuseable system.
- Multimission Modular Spacecraft (MMS) with a PM-II propulsion module; since this system is dedicated to the payload it delivers, it is considered an expendable system in this study.
- Spinning Star 48 (SSUS-D) with an apogee kick stage. The SSUS-D with an apogee kick stage is an adaptation of SSUS-D to provide a two burn capability for low energy payload capability.
- Scout expendable launch vehicle.

All of these approaches, except Scout and OMS, are upper stage concepts that might be used in conjunction with the Shuttle. The Scout launch vehicle delivers the payload from a ground launch to the destination orbit.

### 2.4.1 Performance and Cost Definition

The elements of the launch cost envelope are the performance capability of the existing/planned propulsion approaches and the cost to launch to the destination orbit. Performance of these launch approaches is defined in terms of payload weight delivered and the velocity increment capability above the Shuttle standard circular orbit altitude of 296 km and have been taken from Figure 2.4. Costs to launch the payloads consist of recurring costs of these launch approaches and Shuttle user charges for the launch approach but not for the payload. These costs include:

- Unit acquisition cost for existing/planned launch approaches and Scout.
- Refurbishment costs for recoverable launch approaches.

- Amortization of the unit cost of any additional hardware required to support the low energy regime for recoverable launch approaches already funded.
- Shuttle user costs for existing/planned approaches based on the Shuttle user charge policy.

With these costing groundrules, unit costs for the existing/planned launch approaches were determined using cost data accumulated from the cognizant NASA centers or contractors. Shuttle user charges for the launch approaches were developed from the Space Transportation System Users Handbook.

In the development of user charge the length load factor was determined based on the length or width of the launch approach alone; length is used for horizontal cargo bay installation and width is used for vertical installation. Length of launch approach Airborne Support Equipment (ASE) (cradle) was not included for the following reasons:

- ASE for most of the existing/planned launch approaches was not well defined in the early stages of the Shuttle.
- Any cradle design that occupies significantly more cargo bay length than occupied by the stage will probably be modified to reduce excess user charge.
- Some ASE installation approaches allow other payloads to overlap cradle supports.
- The launch cost envelope serves as a preliminary screening function, consequently it is desirable to keep its use simple.

The weight load factor is based on the weight of the launch approach plus the weight of the ASE including the cradle and launch support equipment. ASE weight was included since it directly impacts the user cost. ASE weights used were derived for the various existing/planned launch approaches as noted:

- OMS - Reference 17 and 18
- TRS - Reference 19
- MMS - Vought MMS cradle installation studies

- Spinning Star 48 Plus AKM - Vought cradle installation studies

An example of the development of total user costs for the envelopes is shown in Table 2-VII for the OMS Kits. Cost development for three versions of the OMS kits including a comparison of length and weight load factors on the Shuttle are shown. User cost is based on the larger of the two factors. Costs are shown for the four standard Shuttle inclinations since costs are a function of these inclinations when the weight load factor is predominant.

### 2.4.2 Launch Cost Envelopes

Six launch cost envelopes were developed for each Shuttle standard orbit inclination and Reference Mission combination using the data derived in paragraph 2.4.1. An example of the data is shown in Figure 2.5 for reference mission D as a plot of user cost in millions of dollars versus velocity increment available from the Shuttle in a 296 km circular orbit. The lowest cost launch approaches establish the envelope for the Shuttle orbit inclinations and Reference Mission payloads. Data for the other launch approaches such as Scout, TRS, MMS and OMS are also shown to depict their relative cost and performance.

TABLE 2-VII USER COSTS FOR OMS KITS

| NUMBER OF KITS | BAY LENGTH M/(FT) | INSTALLED WEIGHT KG/(LB) | LAUNCH INCLINATION DEGREES | LOAD FACTOR LENGTH | LOAD FACTOR WEIGHT | COST FACTOR | USER COST MILLIONS | KIT AND NON-STANDARD ORBIT COST-$M | TOTAL USER COST-$M |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.82/(9.25) | 7401/(16302) | 28.5 | .154 | .251 | .335 | 7.31 | .80 | 8.11 |
| | | | 56 | .154 | .286 | .382 | 8.33 | .80 | 9.13 |
| | | | 90 | .154 | .441 | .588 | 12.84 | .80 | 13.64 |
| | | | 104 | .154 | .544 | .725 | 15.83 | .80 | 16.63 |
| 2 | 2.82/(9.25) | 13379/(29468) | 28.5 | .154 | .453 | .605 | 13.21 | 1.80 | 15.01 |
| | | | 56 | .154 | .517 | .690 | 15.06 | 1.80 | 16.86 |
| | | | 90 | .154 | .797 | 1.06 | 21.83 | 1.80 | 23.63 |
| | | | 104 | .154 | .983 | - | - | - | - |
| 3 | 2.82/(9.25) | 19537/(43033) | 28.5 | .154 | .663 | .884 | 19.29 | 2.80 | 22.09 |
| | | | 56 | .154 | .756 | 1.008 | 21.83 | 2.80 | 24.63 |
| | | | 90 | .154 | 1.16 | - | - | - | - |
| | | | 104 | .154 | 1.14 | - | - | - | - |
| NOTE | 1 | 2 | | | | | 3 | 4 | |

NOTE: 1 - REFERENCE 31
2 - REFERENCE 32
3 - BASED ON 21.834 x $10^6$ DEDICATED USER COST - REFERENCE 22
4 - KIT AND NON-STANDARD ORBIT CHARGE - REFERENCE 32

| NO. KITS | NON-STANDARD ORBIT CHARGE-$M | KIT USE COST-$M | SERIAL IMPACT COST-$M | TOTAL $M |
|---|---|---|---|---|
| 1 | .20 | .27 | .33 | .80 |
| 2 | .20 | .53 | 1.07 | 1.80 |
| 3 | .20 | .80 | 1.80 | 2.80 |

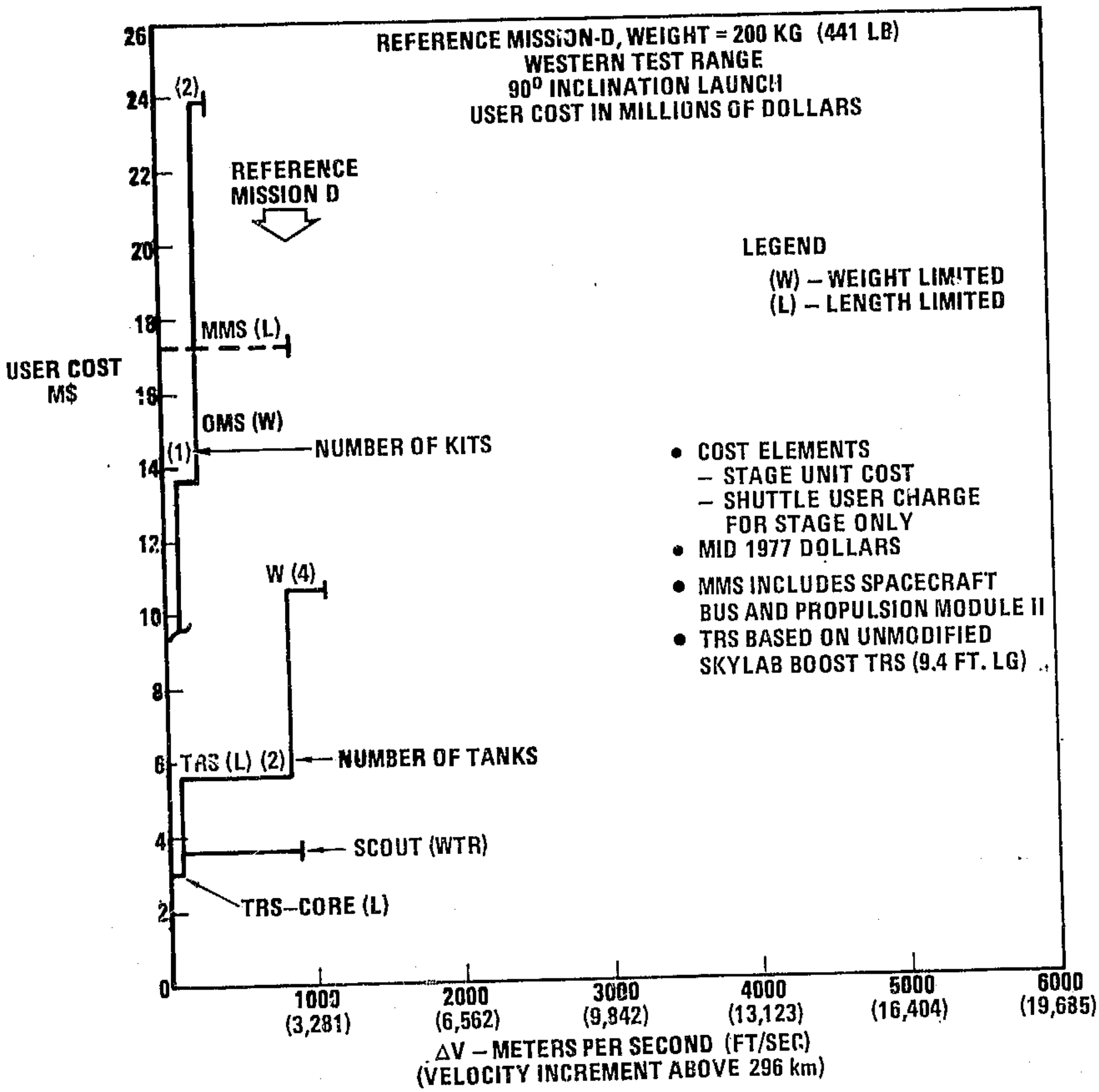



FIGURE 2.5 TYPICAL LAUNCH COST ENVELOPE

## 3.0 TASK 2: FORMULATE AND EVALUATE CANDIDATE PROPULSION MODES

The objective of this task was to formulate and select various propulsion modes for handling the reference missions/payloads of Task 1. Four major activities were required to accomplish this task objective:

(1) Formulate concepts for various propulsion modes - covered in paragraph 3.1 CANDIDATE PAYLOAD - DELIVERY APPROACHES

(2) Develop an effective screening process - detailed in paragraph 3.2 SCREENING METHODOLOGY

(3) Generate concept parametric characteristics for screening - covered in paragraph 3.1 CANDIDATE PAYLOAD - DELIVERY APPROACHES and 3.3 COSTS AND CHARACTERISTICS OF CANDIDATE APPROACHES

(4) Screen and select candidate propulsion modes for conceptual design effort in Task 3 - described in paragraph 3.4 COST/SCREENING ANALYSIS

### 3.1 CANDIDATE PAYLOAD-DELIVERY APPROACHES

The objective of this subtask was to describe the formulation of candidate approaches and establish approach characteristics for screening. Categories of approaches considered include the use or adaptation of existing/planned Shuttle or expendable launch vehicle upper stages and new upper stages.

The approach to formulation of concepts was:

- Reference Missions and payloads A through F from Task 1 were used to determine apogee and perigee velocity requirements.
- Existing or planned approaches which meet these velocity requirements, and are suitable for Shuttle use, were then classified as candidates for subsequent study.
- New approaches including tandem, clustered and controlled solids, liquid bipropellant and mono-

propellant and liquid/solid concepts were selected and sized for appropriate reference mission coverage and details of each were collected. Sufficient detail of other stage equipment, subsystems components and structures was established for performance and sizing.

- Adaptations of existing or planned approaches (which, when combined with new, existing planned approaches are Shuttle compat... also considered.
- The Scout expendable launch vehicle was considered.

The results of this effort provide candidate configurations defined for each reference mission or group of reference missions.

Requirements for an upper stage to transfer a payload from the Orbiter to a destination orbit of higher altitude and/or a difference inclination involves propulsion, attitude control and payload separation. Two impulses in near opposite directions are required: one at perigee and one at apogee. A broad range of propulsive impulses as a function of altitude and/or inclination change are required. For solids some means of impulse adjustment such as a liquid quench system, employment of energy management through inefficient orientation of the thrust vector, or clustered solids is required. Liquid main propulsion systems require a two-pulse capability. The stage must provide an attitude reference from Shuttle ejection to spacecraft separation. A control system must orient the stage for perigee burn and rotate the vehicle approximately 180° for apogee burn 45 minutes to an hour later. Orientation at perigee and apogee out of plane for inclination change and/or in-plane for energy management of solid propulsion systems may be required. Spinning stage concepts may be constrained by payload spin limitations and may require a nutation damper. Three axis stage concepts must provide thrust vector control during perigee and apogee burns in addition to providing pitch, yaw and roll control for coast periods for a wide variety of payloads. Requirements also exist for a payload separation system.

Perigee and apogee velocity increment (ΔV) requirements for each of the reference missions were determined as a function of the amount

of plane change accomplished at perigee and apogee of the transfer orbit. An example of the velocity increments and the total velocity requirements for Reference Mission B are shown in Figure 3.1. There are minimum and maximum $\Delta V$ required based on the distribution of plane change accomplished at perigee and apogee under the assumption of Hohmann orbit transfer. These maximum and minimum $\Delta V$'s are shown in Table 3-I. Reference Mission A does not require a plane change.

TABLE 3-I VELOCITY REQUIREMENTS FOR REFERENCE MISSIONS

| REFERENCE MISSION | REQUIRED PLANE CHANGE (DEG.) | MINIMUM TOTAL DELTA-V MPS (FPS) | MAXIMUM TOTAL DELTA-V MPS (FPS) |
|---|---|---|---|
| A | 0 | 115 (377) | - |
| B | 7 | 991 (3251) | 1160 (3806) |
| C | 1 | 400 (1312) | 421 (1381) |
| D | 6.5 | 879 (2884) | 963 (3159) |
| E | 25.6 | 3290 (10794) | 3692 (12113) |
| F | 41.5 | 5239 (17189) | 5733 (18809) |

### 3.1.1 Existing/Planned Approaches

To establish viable existing/planned approaches it was necessary to examine and establish characteristics of a variety of approaches and screen out approaches which were not applicable for the Shuttle. This procedure is described in the following paragraphs.

3.1.1.1 Candidate Existing/Planned Approaches - Existing or planned propulsion systems considered as potential approaches for the LES Study include three systems planned for the STS and the Scout expendable launch vehicle (ELV). Integral OMS capability, as well as the added velocity available from up to three OMS kits, provide capability in the very low velocity region of the LES regime. Two and four tank versions of the Teleoperator Retrieval System (TRS), as both reuseable and expendable upper stages, have potential in the medium weight-low velocity region. The Multimission Modular Spacecraft (MMS), while primarily oriented toward on-orbit support to payloads

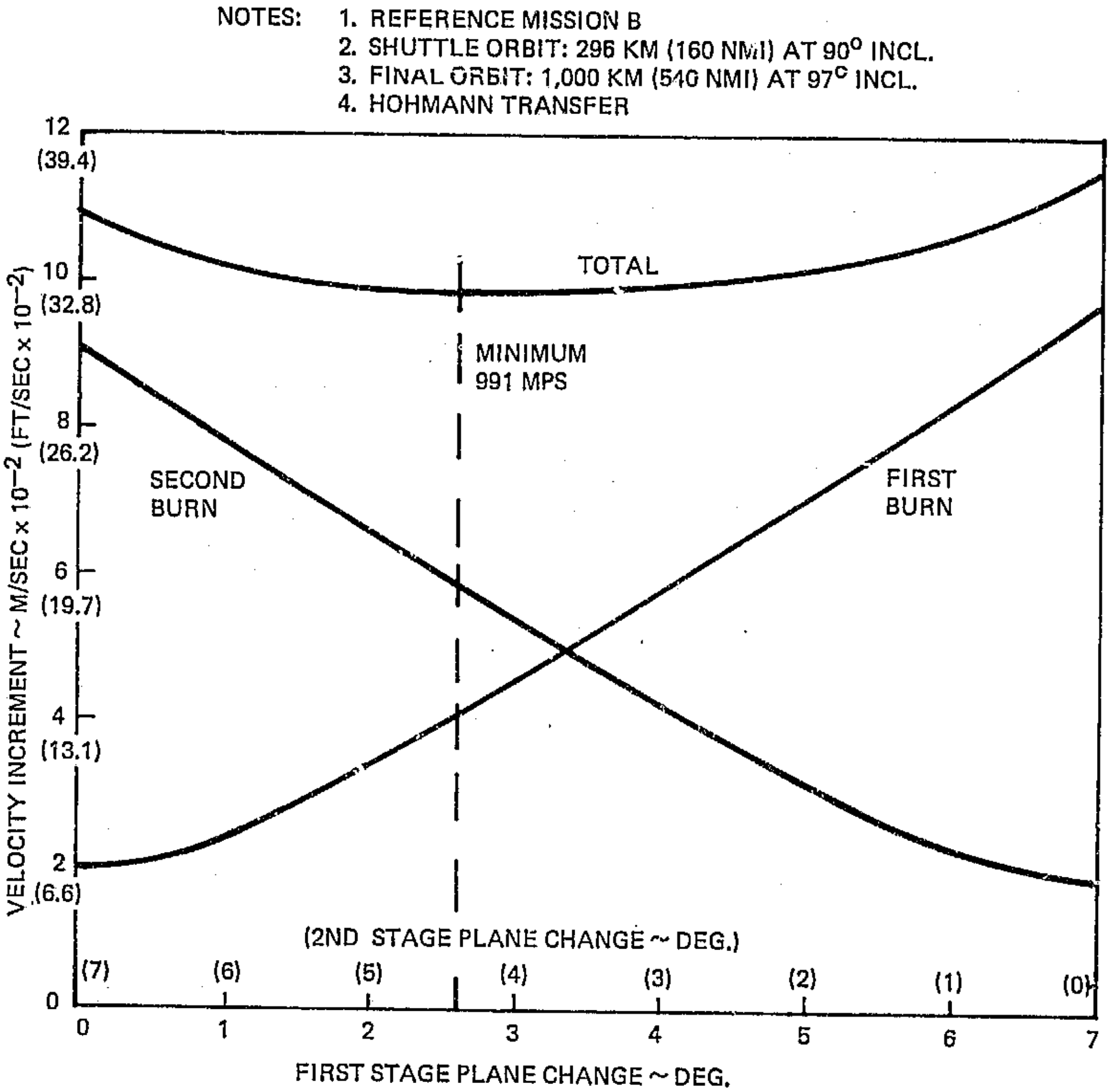



FIGURE 3.1 TYPICAL REFERENCE MISSION VELOCITY REQUIREMENTS

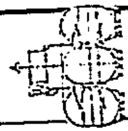
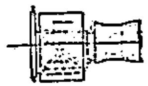
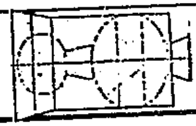
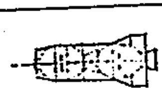
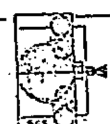
and payload return to the Orbiter, may be used to transfer from the Orbiter to the payload orbit.

Potential existing/planned systems include two planned for the STS - the Spinning Minuteman Third Stage (SSUS-A) and a Spinning Star 48 (SSUS-D) stage. Other ELV upper stages are the Global Positioning System, the Block 5D, Burner IIA and the Satellite Control Section.

3.1.1.2 Screening of Approaches - Figure 3.2 provides sketches of each candidate existing/planned approach, physical size and weight, energy capability, apogee energy capability, and attitude control system availability. The TRS and MMS/PMII appear attractive for low energy payload transfer and were considered in the final screening in Task 6 of Volume IV. The Spinning Star 48 (SSUS-D) and Spinning MM III (SSUS-A) are relatively compact and possess adequate energy for booster application of a low energy stage and were considered as "adaptations" in the study. The Inertial Upper Stage (IUS) is much too large for the low energy regime and was not considered further. The two-stage Burner IIA ELV upper stage system has been out of production since 1974 and none are currently available. For this reason it was not considered further in this study. The Block 5D ELV upper stage is quite long for its energy capability in comparison to the spinning stages and its cost is high, and was therefore not considered further in this study as a candidate. The Global Positioning System (GPS) is long for its energy capability and has no guidance and control system and therefore was not considered further in this study. The Satellite Control Section is primarily a satellite support concept. It provides power communications and other functions as well as modules to house instruments and experiments. The monopropellant propulsion system mass fraction is quite low. For these reasons, this system was not considered further in the study. In Figure 3.2, the top four approaches were selected for further study and included in the final screening in Task 6 of Volume IV.

3.1.2 New Propulsion Approaches

This section addresses candidate new propulsion approach identification and initial screening, candidate subsystems, sizing of candidate approaches and characteristics of approaches. Emphasis was placed on configuring new approaches into compact, well integrated stages which reduce Shuttle installation length while using existing hardware or proven technology.

| | UPPER STAGE | NAME | LENGTH M (FT) | DIA. M (FT) | STAGE WT. Kg (LB) | ΔV (1) M/SEC (FT/SEC) | HAS AKM | HAS ACS | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| STS UPPER STAGES |  | TRS | 2.0 (0.4) | 3.048 (10.0) | 4153 (9,156) | 1000 (3281) | YES | YES | CONSIDER IN TASK 6 AS RETRIEVABLE OR EXPENDABLE |
| |  | MMS/PMII | 3.048 (10.0) | 2.195 (7.2) | 1207 (2,660) | 510 (1673) | YES | YES | ALLOCATE COST TO PAYLOAD & STAGE–CONSIDER IN TASK 6 |
| |  | SSUS-D | 2.103 (6.9) | 1.402 (4.6) | 1936 (4268) | 2452 (8043) | NO | NO | CONSIDER AN ADAPTATION |
| |  | SSUS-A | 2.225 (7.3) | 1.554 (5.1) | 3743 (8251) | 3386 (11,110) | NO | NO | CONSIDER AN ADAPTATION |
| |  | IUS (TWO-STAGE) | 4.542 (14.9) | 3.170 (10.4) | 14,515 (32,000) | 6248 (20,500) | YES | YES | TOO LARGE FOR LES REGIME– NOT CONSIDERED FURTHER |
| ELV UPPER STAGES |  | BURNER II A | 2.408 (7.9) | 1.615 (5.3) | 1125 (2480) | 1560 (5118) | YES | YES | NONE AVAILABLE; USES $H_2O_2$ – NOT CONSIDERED FURTHER |
| |  | BLOCK 5D | 3.444 (11.3) | 1.615 (5.3) | 2016 (4444) | 2458 (8064) | YES | YES | LONG FOR ENERGY COMPARED TO SPINNING STAR 48 – NOT CONSIDERED FURTHER |
| |  | GPS | 3.383 (11.1) | 1.433 (4.7) | 2438 (5375) | 2813 (9229) | YES | NO | NO ACS OR G&C; LONG FOR ENERGY – NOT CONSIDERED FURTHER |
| |  | SATELLITE CONTROL SECTION | 2.469 (8.1) | 3.048 (10.0) | 2825 (6228) | 926 (3038) | YES | YES | BUS CONCEPT, LONG, LOW MASS FRACTION – NOT CONSIDERED FURTHER |

(1) VELOCITY CAPABILITY FOR 1000 Kg (2205 lb.) PAYLOAD

FIGURE 3.2 EXISTING/PLANNED APPROACHES AND ADAPTATIONS

3.1.2.1 New Propulsion Approaches - Candidate new propulsion approaches which satisfy reference missions requirements were identified and screened. This section provides rationale for and results of this effort. Propulsion system characteristics considered desirable for screening purposes are: short length, low weight, good performance, low unit cost, low development cost and risk, high reliability and wide off-design performance capabilities through impulse variability.

(a) Identification of Candidate Concepts - Six basic types of propulsion approaches considered candidates are tandem solid, clustered solid, controlled solid, liquid bipropellant, liquid monopropellant and liquid/solid.

- Tandem Solid - This expendable launch vehicle approach utilizes off-the-shelf and/or new conventional solid motors with class 2 propellants. Because of the wide range of total impulse available from existing motors, new design motors were not considered necessary. Modifications were limited to shortening of the exit cone to an expansion ratio of 30:1. For length-limited applications, long exit cones usually present on ELV upper stage motors are not desirable.
- Clustered Solid - Solid motors are clustered as required to meet the velocity requirements. Potential problems of thrust misalignment resulting from differences in ignition and propellant burn rate were considered significant but the short stage length achievable made this concept attractive. Flat pack concept has motors clustered normal to the vehicle longitudinal axis in order to reduce vehicle length and decrease thrust misalignment problems inherent in the conventional cluster approach. Nozzles are placed as close to the centerline as practical and canted to direct the thrust through the vehicle center of gravity. To reduce control force due to thrust misalignment, low thrust and end burning motors can be used. To reduce cost, relatively inexpensive cartridge loaded grains

are desirable. Total impulse variability is achieved by varying the number of motors and propellant grain length.

- <u>Controlled Solids</u> - If start-stop, start-stop capability is available, a single solid motor can be used for both apogee and perigee burns. This results in a significant length reduction over a solid solid tandem configuration. Thrust extinguishment with reignition capability can be achieved by use of pintle nozzle, liquid quench and liquid/solid hybrid configurations.

(1) <u>Pintle Nozzle</u> - Pintle nozzle technology is probably the most fully developed of all the variable impulse concepts. A special propellant blend of slightly lower performance than conventional propellants is normally used. This concept is capable of stop and restart at any time during the burn. Inadvertent reignition is not possible with the pintle open in a properly designed system.

(2) <u>Liquid Quench</u> - Liquid quench technology has been demonstrated with non-class 2 propellants but has not yet been developed. Most quench motors cannot be quenched over the full operating range, thus small and large motors or stage energy management may be required to cover a broad mission spectrum.

(3) <u>Liquid/Controlled Solid</u> - Technology has been developed in which a solid motor will only sustain combustion with the addition of a liquid. This concept has been demonstrated on the High Altitude Supersonic Target vehicle. System complexity and development effort required make this concept less attractive than the pintle nozzle and the liquid quench.

(4) <u>Dual Pulse</u> - Two discrete burns can be achieved with an end burning motor by placing a barrier in the grain at a predetermined point. This concept has been developed in a small diameter missile.

- Liquid Bipropellant - This concept consists of multi-propellant and pressurant tankage arranged for low length to diameter ratio, a single short central main thruster, and one or more maneuver or nutation control thrusters with common feed system. One basic configuration is sized to meet high energy mission requirements with low energy derivatives in which propellant and/or tankage is deleted. Proven thrusters, system hardware and technology are available. New propellant tankage using proven technology and tailored for compact packaging, provide good modularity potential.
- Liquid Monopropellant - This concept also consists of multi-propellant and pressurant tankage arranged for low length to diameter ratio but utilizes four thrusters which also function as maneuver or nutation control. One basic configuration is sized for high energy missions with low energy derivatives where propellant or tankage is removed. Proven thrusters, hardware and technology are available. New propellant tankage incorporating proven technology and tailored for compact packaging, also provide good modularity. The monopropellant system is less complex and lower in cost but lower in performance than the bipropellant concept for similar size systems.
- Liquid/Solid - This concept offers the high mass fraction and bulk density advantages of the solid along with the packaging and impulse variability capabilities of the liquid. A conventional solid is used for the first velocity increment and a liquid packaged compactly around the solid is used for the second increment. Adaptations in which existing/planned motors are used are compatible with this concept.

(b) Screening of Candidate Concepts - Advantages and disadvantages of each candidate system are summarized in Table 3-II, and form the basis for initial screening. Most of the candidate systems are retained.

TABLE 3-II CANDIDATE PROPULSION APPROACHES

| SYSTEM | ADVANTAGES | DISADVANTAGES | RETAINED AS CANDIDATE FOR TASK 2 |
|---|---|---|---|
| Tandem Solid | • Off-the-shelf qualified hardware and technology<br>• High performance and mass fraction<br>• Length efficient for vertical payloads<br>• Compatible with solid adaptations<br>• Conventional stage design | • Length inefficient for horizontal payloads<br>• Poor impulse variability<br>• Two stage complexity<br>• May be inaccurate with energy management | • Yes |
| Clustered Solid | • Length efficient for horizontal or vertical payloads<br>• Off-the-shelf technology<br>• High performance<br>• Good impulse variability<br>• Single stage simplicity | • Poor mass fraction<br>• Motor and thrust control likely a problem<br>• Development/qualification for new motor size as required<br>• Unconventional design<br>• Not compatible with solid adaptations<br>• CG control may be a problem | • Yes |
| Controlled Solids<br>- Liquid Quench<br>- Pintle Nozzle<br>- Liquid Control Solid<br>- Two Pulse Solid | • Length moderate for horizontal payloads<br>• High performance and mass fraction<br>• Compatible with solid adaptations<br>• Conventional stage design<br>• Basic technology proven<br>• Single stage simplicity<br>• Good impulse variability (pintle and liquid control)<br>• More extensive technology development for liquid quench and pintle nozzle | • Extensive development/qualification required<br>• Relatively high risk program | • Yes - Liquid Quench & Pintle Nozzle<br>• No - Liquid Control Solid and Two Pulse Solid |

TABLE 3-II CANDIDATE PROPULSION APPROACHES (CONT'D)

| SYSTEM | ADVANTAGES | DISADVANTAGES | RETAINED AS CANDIDATE FOR TASK 2 |
|---|---|---|---|
| Liquid Bipropellant | • Off-the-shelf qualified hardware and technology<br>• Length efficient for horizontal or vertical payloads<br>• High performance<br>• Single stage simplicity<br>• Good impulse variability<br>• Packaging flexibility | • Fairly low mass fraction<br>• More complex than most solids and monopropellant system | • Yes |
| Liquid Monopropellant | • Off-the-shelf qualified hardware and technology<br>• Length efficient for horizontal or vertical payloads<br>• Less complex than bipropellant but more than most solids<br>• Single stage simplicity<br>• Good impulse variability<br>• Packaging flexibility | • Low mass fraction<br>• Low performance | • Yes |
| Liquid/Solid | • Off-the-shelf qualified hardware and technology<br>• Moderate performance and mass fraction<br>• Good impulse variability<br>• Packaging Flexibility | • Length inefficient due to solid<br>• Complex two stage system | • Yes |

Exceptions are the liquid controlled and dual pulse solids. The liquid controlled solid was deleted because more technology development effort has been expended on the competitive pintle and liquid quench concepts. Since the dual pulse solid has a large diameter, development risk for the barrier and second ignition is relatively high. Impulse of this concept is inflexible.

3.1.2.2 Candidate Subsystems - This section identifies the candidate subsystems and components assumed and baselined for Task 2. Included are main propulsion, guidance, electrical, structure, RCS, other miscellaneous stage hardware, and ASE. Each subsystem discussion addresses all the concepts except where specifically noted.

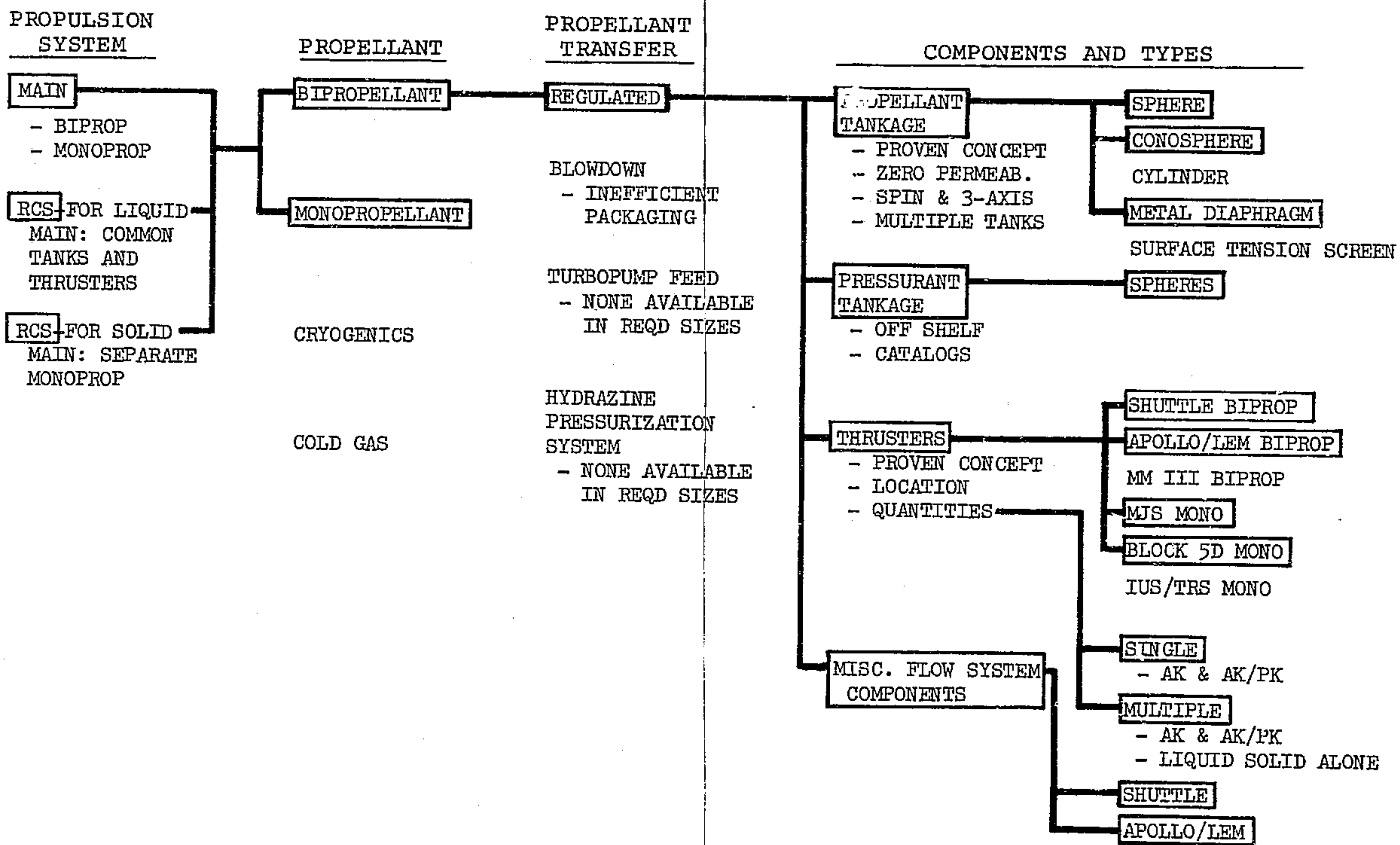
Liquid Propulsion - Liquid main and RCS propulsion system considerations of propellant type, propellant transfer and components are illustraded in Table 3-III. Liquid system, subsystems and components baselined for Task 2 are those enclosed by boxes in Table 3-III. For instance, spherical and conospherical propellant tankage incorporating metal diaphragms were used in studies. Size, weight and functional characteristics of the liquid systems are defined in 3.1.2.3 and 3.1.2.4 for a typical system.

Solid Propulsion - Solid main propulsion system hardware, technology and formulation rationale are described in Table 3-IV. Formulation approaches baselined and accompanying rationale are identified by box enclosures in Table 3-IV. Characteristics are described in 3.1.2.3 and 3.1.2.5 for a typical system.

Guidance and Control System - Based on payload accuracy requirements from Task 1, an error budget was established. At this point in the study it was determined that LES must accumulate no more than one (1) degree additional attitude error from the time it is deployed from the Orbiter until the payload is injected into its final orbit. The duration of the LES flight from deployment to payload injection can be as long as 1-1/2 to 2 hours. In addition to satisfying these requirements and the stage functional requirement, the system must also handle command functions, signal conditioning, nutation damping or three axis stabilization as required. The systems meeting the qualification criteria that were considered are the Ball Brothers STRAP, Ball Brothers DACS, the Space Vector MIDAS (Hawkeye), and the Teledyne SOFT/DOT. The evaluation of these systems is shown in Table 3-V.

Based on the systems considered, the Teledyne SOFT/DOT system with the dry-tuned flexure gyros on a roll stabilized platform was selected

TABLE 3-III LIQUID PROPULSION CANDIDATE SUBSYSTEMS AND COMPONENTS



## TABLE 3-IV CANDIDATE SOLID PROPULSION HARDWARE/TECHNOLOGY

| PROPULSION SYSTEM | | HARDWARE/ TECHNOLOGY | | CONFIGURATION |
|---|---|---|---|---|
| SOLID TANDEM | | OFF-THE-SHELF<br>THIOKOL<br>AEROJET<br>CSD | | VEHICLE CONFIGURED FROM EXISTING MOTORS |
| | | ADVANCED TECHNOLOGY | CONSIDERED UNNECESSARY | |
| CONTROLLABLE IMPULSE | PINTLE | TECHNOLOGY PROGRAMS<br>AEROJET<br>THIOKOL | | NEW DESIGN |
| | QUENCH | TECHNOLOGY PROGRAM<br>HERCULES | | NEW DESIGN |
| | HYBRID | TECHNOLOGY PROGRAM<br>HERCULES | LESS DESIRABLE THAN PINTLE OR QUENCH | |
| DUAL PULSE | | SHRAM<br>THIOKOL<br>ARC | UNSUITED FOR BROAD MISSION SPECTRUM | |
| CONVENTIONAL CLUSTER | | OFF-THE-SHELF<br>THIOKOL<br>AEROJET | | VEHICLE CONFIGURED FROM EXISTING MOTORS |
| FLAT PACK | | TECHNOLOGY PROGRAM<br>ARC | | NEW DESIGN |

## TABLE 3-V CANDIDATE GUIDANCE SYSTEMS

| SOURCE | STATUS | EVALUATION |
|---|---|---|
| **SPACE VECTOR**<br>MIDAS Platform (2-DOF Gyros) | Flight Qualified on Hawkeye (Scout S-191) | - Drift rate 30°/hour (3 sigma)<br>- Not practical to modify to decrease drift rate<br>- Unacceptable |
| **BALL BROTHERS**<br>DACS | One unit produced and qualification tested for Kitt Peak National Observatory. Program terminated before flight. | - Drift rate 2°/hour (3 sigma)<br>- Not flight qualified<br>- Unacceptable |
| **TELEDYNE**<br>SOFT/DOT (Dry, Tuned Flexure Gyros) | Flight qualified on SOFT | - Drift rate 0.03°/hour (3 sigma)<br>- 1969-1970 design requires modernization for long term program<br>- Acceptable for spin stab. LES |
| SCOUT (Dry, Tuned Flexure Gyros) | Presently being developed to meet the NASA Scout Phase VIII guidance and control requirements. | - Drift rate 0.03°/hour (3 sigma)<br>- Acceptable for 3-axis LES |

for the spin stabilized stages. This system was flight qualified on the SOFT program, has adequate accuracy (0.03 degree/hour drift rate, 3 sigma), and can provide all command functions and signal conditioning. This same system, without the roll stabilized platform, has been repackaged and is being qualified for the NASA Scout program and this configuration was selected for the 3-axis stabilized LES stages. The system selected for the spin stabilized stage consists of four packages and weighs 24.7 kg (54.5 lbs.). The dimensions of each component are:

- Roll Stabilized Platform, 17.78 cm dia. x 24.765 cm (7 in. dia. x 9.75 in.)
- Platform Electronics, 30.5 cm x 23.57 cm x 14.3 cm (12.03 in. x 9.28 in. x 5.63 in.)
- Computer, 45.8 cm x 25.17 cm x 11 cm (18.03 in. x 9.91 in. x 4.33 in.)
- Thruster Electronics, 7.62 cm x 10.16 cm x 8.89 cm (3 in. x 4 in. x 3.5 in.)

The system selected for the 3-axis stabilized stage configurations is contained in a single package and weighs 20.3 kilograms (44.8 pounds). This package is 28.6 cm x 39.37 cm x 19.6 cm (11.26 in. x 15.5 in. x 7.7 in.).

For attitude control of the spin stabilized LES configurations, one or two reaction control system (RCS) thrusters are required to provide the control force for nutation damping and for reorientation. Configurations with ratio of roll inertia to pitch inertia of the stage plus payload between 0.5 and 1.5 require two reaction control thrusters. For 3-axis stabilized configurations, four thrusters are used for attitude control. These thrusters were canted at 45 degrees and provide control about pitch, yaw and roll axes. The control analysis to establish RCS thrust requirements is detailed in paragraph 4.0.

Telemetry System - For the housekeeping and performance telemetry system, a Conic Corporation Model CTM-UHF-310E, 8 watt, S-band transmitter was selected. This unit weighs 0.91 kg (2 lbs.), is 11.7 cm x 3.5 cm x 11.7 cm (4.62 in. x 1.38 in. x 4.62 in.) and is typical of space qualified hardware available. A Ball Brothers wrap-around antenna, similar to the NASA Scout 23-004131 antenna was selected as being typical of space qualified antennas available for use in telemetry systems. This antenna weighs 0.57 kg (1.25 lbs.). Since the required signal conditioning and data formating is available in the guidance system computer, no separate signal conditioner is required.

Electrical Power and Cabling and Ignition System - Electrical power is provided by an automatically activated silver-zinc battery. The estimated power requirements for the stage are shown in Table 3-VI. It is

TABLE 3-VI ELECTRICAL POWER REQUIREMENTS

| COMPONENT OR SYSTEM | VOLTAGE | CURRENT (AMPS) | POWER (WATTS) | TIME (HRS) | ENERGY (WATT-HOURS) |
|---|---|---|---|---|---|
| ACS Electronics | 28 | 4.28 | 119.84 | 1.5 | 179.76 |
| RCS Valves | 28 | 1.0 | 28 | 0.15 | 4.2 |
| Timers (10) | 28 | .035 | 0.98 | 1.5 | 1.47 |
| Relays (10) | 28 | 0.62 | 17.36 | .00277 | 0.0482 |
| Propulsion Valves | 28 | 2.0 | 56 | .08333 | 4.67 |
| Telemetry Transmitter | 28 | 3.6 | 100.8 | 1.5 | 151.2 |
| Average Power | | | 227.57 | | |
| Total Energy | | | | | 341.35 |

estimated that an automatically activated silver-zinc battery, which provides these requirements with a twenty percent reserve, weighs 14.52 kg (32 lbs) and has dimensions of 12.7 cm x 17.8 cm x 33.0 cm (5 in. x 7 in. x 13 in.). The electrical cabling is estimated to be similar in quantity and complexity to that being used in Scout Lower D Section which weighs 11.3 kg (25 lbs.). The ignition system consists of:

(a) An Ignition Control Unit containing firing capacitors, firing switches and safe arm relays - this unit is estimated to weigh 1.54 kg (3.4 lbs) and occupies 1737 cc (106 cu.in.).

(b) A sequencer for initiating ignition firing commands - for this preliminary system definition, Model 4100 timers manufactured by Cyclomatic Industries, Inc. are selected to fulfill the sequencer function. For

solid systems, eight of these timers are required whose total weight is 1.36 kg (3.0 lbs.) and whose volume is 688 cc (42 cu.in.). For liquid systems ten timers are required whose total weight is 1.7 kg (3.75 lbs.) and whose volume is 852 cc (52 cu.in.).

(c) Deployment switches for starting the timers at deployment of the stage - to satisfy redundancy and safety requirements six deployment switches are used. They are similar to Microswitch 602EN126-6 switches. The weight of the six switches is .52 kg (1.14 lbs.).

The total weight for the ignition system is approximately 3.4 kg (7.5 lbs.) for solid stages and 3.8 kg (8.3 lbs.) for liquid stages.

Structure - Structural concepts selected are:

- Two Stage Solid/Liquid Propulsion
  - Booster Stage - Conventional Monocoque
  - Delivery Stage - Combination Truss and Sandwich
- Two Stage Solid/Solid Propulsion - Conventional Monocoque
- Controlled Solid Propulsion - Conventional Monocoque
- Clustered Solid Propulsion - Combination Truss and Sandwich
- Liquid Propulsion - Combination Truss and Sandwich

The combination truss and sandwich construction employs truss members as primary load bearing structure and the sandwich for subsystem and component mounting. The parametric structural weight equations in Table 3-VII were derived empirically from Shuttle upper stage data available from previously completed studies. Weight derived from these equations includes structure, stage and payload separation provisions, payload and interstage adapters and bracketry and is based on aluminum construction.

Reaction Control System (RCS) - A separate monopropellant RCS was considered for solid propulsion systems. All liquid systems consider use of either bipropellant or monopropellant RCS which shares tankage with the main propulsion system. For spin stabilized systems, a total impulse capability of 32025 N-sec (7200 $lb_f$-sec) was used based on prior studies. Three axis systems were also used to provide the same total impulse capability. The number of maneuver/nutation thrusters for spin systems and for the three

TABLE 3-VII

PARAMETRIC STRUCTURAL WEIGHT FOR
CANDIDATE NEW PROPULSION APPROACHES

| PROPULSION APPROACH | PARAMETRIC STRUCTURAL WEIGHT - Kg |
|---|---|
| Two Stage Solid/Liquid | |
| - Booster Stage | $.49\ (Wp_1)^{1/2} + .63\ (Wp_1)1/3$ |
| - Delivery Stage | $.73\ (Wp_1 + Wp_2)^{1/2} + 7.71$ |
| Two Stage Solid/Solid | |
| - Booster Stage | $1.24\ (Wp_1)^{1/2} + .61\ (Wp_1)^{1/3}$ |
| - Delivery Stage | $.82\ (W_{p_1} + W_{p_2})^{1/2} + 7.71$ |
| Controlled Solid | $.82\ (Wp)^{1/2} + 7.71$ |
| Clustered Solid | $4.52\ (Wp)^{1/2} + 7.71$ |
| Liquid | $1.21\ (Wp)^{1/2} + 7.71$ |

Wp = Weight of propellant

$Wp_1$ = Weight of propellant - First Stage

$Wp_2$ = Weight of propellant - Second Stage

axis system were described previously. Thrust levels were 445 N (100 $lb_f$) for bipropellant and 623 N (140 $lb_f$) for monopropellant systems based on use of existing hardware and prior studies. Characteristics of the RCS are shown in Tables 3-VIII, 3-IX, and 3-X and a typical separate monopropellant RCS schematic is given in Figure 3.3.

Thermal, Destabilization, Spin Balance and Contingency - Thermal blankets, heaters and control hardware, etc. weight was estimated to be 2.3 kg (5 $lb_m$) and is independent of size or type propulsion system. In addition, a destabilization and spin balance weight allowance of 9 kg (20 $lb_m$) was assumed for both spin and three-axis stabilized stages.

Airborne Support Equipment Weight - The weight for the Airborne Support Equipment for use in the determination of Shuttle user charge for the candidate propulsion approaches was derived as a function of the stage weight from the following equation.

$$\text{Weight of ASE (kg)} = .151 \times \text{weight of stage} + 505$$

TABLE 3-VIII SEPARATE MONOPROPELLANT REACTION CONTROL SYSTEM

| | |
|---|---|
| CHARACTERISTICS | – Propellant carried in separate tanks, separate thrusters, lines and instrumentation |
| PROPELLANT | – $N_2H_4$ |
| TOTAL IMPULSE | – 32,025 N-sec (7200 $lb_f$-sec) |
| WEIGHT, TOTAL | – 35.2 kg (77.6 lbm) (Mission B) |
| USABLE PROPELLANT | – 16.3 kg (36.0 lbm) |
| THRUST LEVEL | – to 689 N (155 $lb_f$) |
| SPECIFIC IMPULSE | – 1961 m/sec (200 $lb_f$-sec/lbm) (Mission Average) |
| SIZE | – Propellant Tank – 33.5 cm (13.2 in.) sphere<br>– Pressurant Tank – 24.4 cm (9.6 in.) sphere<br>– Thruster (R-30A) – 11.76 cm (4.4 in.) dia, 27.9 cm (11 in.) length |
| NO. THRUSTERS | – Mission A – 4, Mission B – 1, Mission C – 2, Mission D – 2, Mission E – 2, Mission F – 2 |

TABLE 3-IX COMMON BIPROPELLANT REACTION CONTROL SYSTEM

| | | |
|---|---|---|
| CHARACTERISTICS | - | Propellant carried in main tanks; separate thrusters, lines and instrumentation |
| PROPELLANT | - | $N_2O_4$/MMH |
| TOTAL IMPULSE | - | 32,025 N-sec (7200 $lb_f$-sec) |
| WEIGHT, TOTAL | - | 2.3 kg (5.0 lbm) (Mission B) |
| RCS PROPELLANT ALLOWANCE | - | 13.6 kg (30 lbm) |
| THRUST LEVEL | - | 445 N (100 $lb_f$) |
| SPECIFIC IMPULSE | - | 2354 m/sec (240 $lb_f$-sec/lbm) (Mission Average) |
| SIZE | - | Common propellant and pressurant tankage varies with mission |
| | - | Thruster 15.2 cm (6 in.) dia., 34.0 cm (13.4 in.) length R-4D |
| NO. THRUSTERS | - | Mission A - 4<br>Mission B - 1<br>Mission C - 2<br>Mission D - 2<br>Mission E - 2<br>Mission F - 2 |

TABLE 3-X COMMON MONOPROPELLANT REACTION CONTROL SYSTEM

| | |
|---|---|
| CHARACTERISTICS | - Thrusters for RCS are main thrusters; propellant is carried in main propellant tanks |
| PROPELLANT | - $N_2H_4$ |
| TOTAL IMPULSE | - 32,025 N-sec (7200 $lb_f$-sec) |
| WEIGHT, TOTAL | - 0 |
| RCS PROPELLANT ALLOWANCE | - 16.3 kg (36 lbm) |
| THRUST LEVEL | - to 633 N (140 $lb_f$) |
| SPECIFIC IMPULSE | - 1961 m/sec (200 $lb_f$-sec/lbm) (Mission Average) |
| SIZE | - Common propellant and pressurant tankage varies with mission<br>- Thruster 11.9 cm (4.7 in.) dia., 39.4 cm (15.5 in.) length (main thruster) MR-104 |

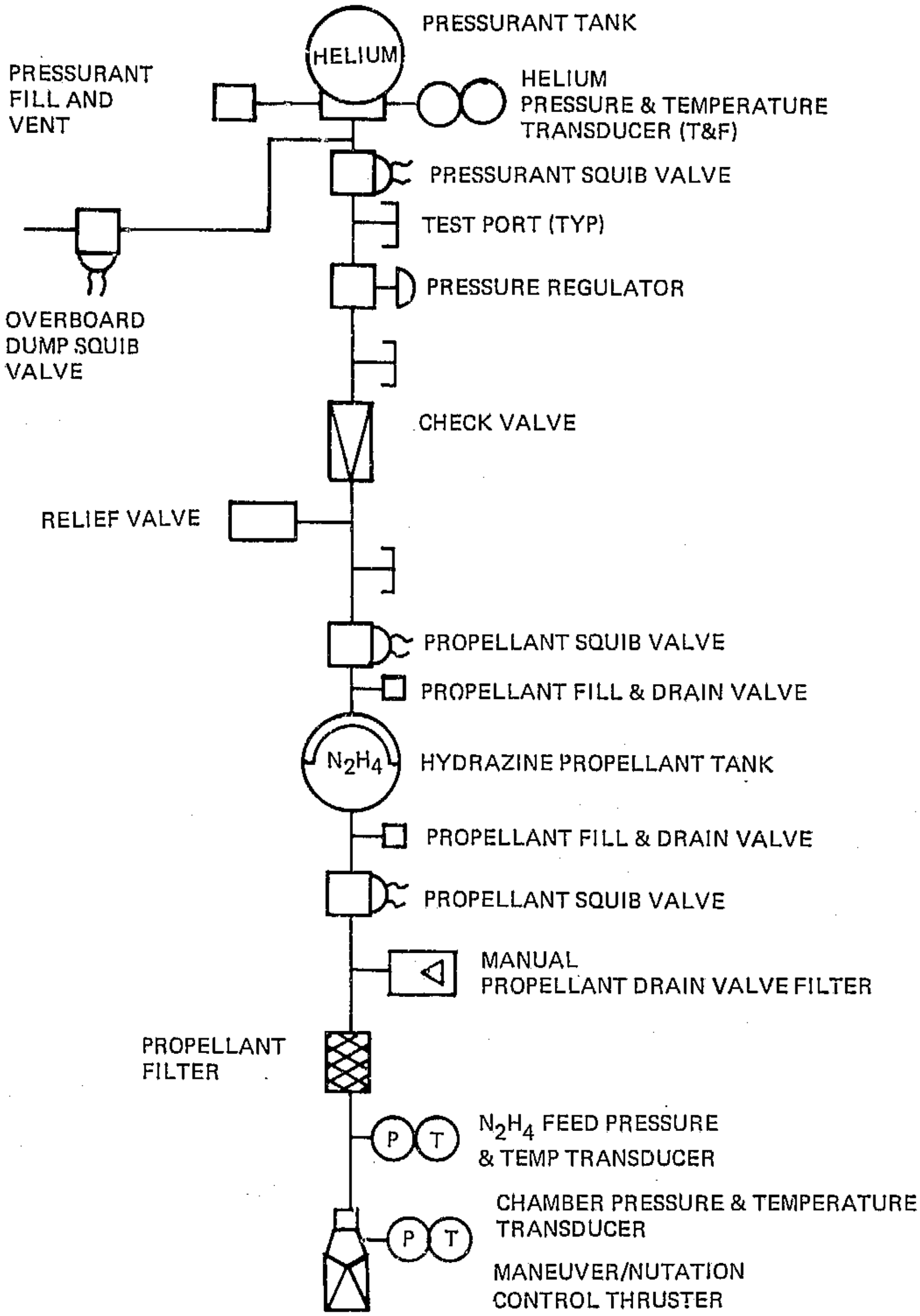



FIGURE 3.3 MONOPROPELLANT RCS SCHEMATIC

This equation was derived empirically on a least square curve fit to a plot of ASE weight versus stage weight for SSUS-D, SSUS-A, MMS, TRS and other ASE point design weight studies.

Vehicle/Configuration Weight Summary - Each of the subsystem weights described are combined with other vehicle weights and shown later in Figure 3.6. For contingency allowance purposes, ten percent of the stage inert weight, exclusive of main propulsion, was assumed to account for stage component weight variations and potential use of alternate lower cost hardware.

3.1.2.3 Candidate Approach Synthesis - Preliminary screening of new propulsion approaches and identification of candidate subsystems baselined the candidate stage hardware possibilities. Considering the remaining approaches, subsystems and reference mission energy levels, a potentially large number of stages still remained. However, by formulation and synthesis of approaches to maximize mission coverage, minimize stage length, and maximize use of adaptations of existing/planned hardware, the most desirable stages were selected.

Solid/Solid Tandem - This approach is governed primarily by availability of appropriate existing/planned motor or stage performance capabilities. Perigee motors selected for the high energy reference missions were the Spinning MM III (SSUS-A) as an upper limit, the Star 37 as the lower limit and the Spinning Star 48 (SSUS-D) as a mid-point. Motors smaller than the Star 37 were too small to affect high energy capture. Early in the screening process it was found that the Spinning MM III (SSUS-A) was so large as to have much poorer off mission capture capability than the Star 37 and the Star 48 (SSUS-D) and it was dropped from further consideration in this study. Two configurations which satisfy reference mission B were synthesized as propulsion group 1 (Table 3-XI) consisting of a Spinning Star 48/Solid AKM and group #3 consisting of a Star 37/Solid AKM. Two solid AKM's were considered for group #1. A single configuration for reference mission F (group #2) consists of a Spinning Star 48 with Solid AKM.

Clustered Solid - The clustered approach is also limited by existing motor capability. Group 5 was planned for this approach. The flat pack endburner approach (group 4) was conceived during Vought in-house studies. These studies show that a realistic maximum number of motors is six and that mission coverage is achieved by either reducing grain length, case length,

TABLE 3-XI PROPULSION MODE APPROACH DEFINITION

| APPROACH | PROPULSION GROUP NO. AND IDENTIFICATION | ADAPTATION OR NEW APPROACH | SIZING REFERENCE MISSION | OTHER MISSION COVERAGE EXPECTED |
|---|---|---|---|---|
| SOLID/SOLID TANDEM | 1. STAR 48/SOLID AKM | ADAPTATION | B | A,C,D,E |
| | 2. MINUTEMAN 3RD STAGE SOLID AKM | ADAPTATION | F | – |
| | 3. STAR 37/SOLID AKM | NEW | B | A,C,D,E |
| SOLID/SOLID CLUSTER | 4. FLAT PACK – END BURNING | NEW | B | A,C,D |
| | 5. CLUSTERED LOW L/D CONVENTIONAL MOTOR | NEW | B | A,C,D |
| CONTROLLED SOLID | 6. LIQUID QUENCH | NEW | B | A,C,D |
| | 7. PINTLE NOZZLE | NEW | B | A,C,D |
| SOLID/LIQUID | 8. STAR 48/BIPROPELLANT | ADAPTATION | B | A&E/C&D* |
| | 9. STAR 48/MONOPROPELLANT | ADAPTATION | B | A&E/C&D* |
| | 10. MINUTEMAN 3RD STAGE OR STAR 48/ **MODULAR BIPROPELLANT | ADAPTATION | F | – |
| | 11. MINUTEMAN 3RD STAGE OR STAR 48/ ***MODULAR MONOPROPELLANT | ADAPTATION | F | – |
| | 12. MODULAR STAR 37/BIPROPELLANT | NEW | B | A&E/C&D |
| LIQUID | 13. MODULAR BIPROPELLANT | NEW | B | A,C,D |
| | 14. MODULAR MONOPROPELLANT | NEW | B | A,C,D |

*FULL PROPULSION GROUP NO. FOR A&E; UPPER STAGE FOR C&D

**CONFIGURED FROM PROPULSION GROUP NO. 13 HARDWARE

***CONFIGURED FROM PROPULSION GROUP NO. 14 HARDWARE

number of motors, or a combination of these.

Controlled Solid - Mission coverage for the pintle nozzle and liquid quench motors is assumed to be provided by a single motor sized for Reference Mission B. Group #6 identifies the liquid quench and group #7 the pintle nozzle motor configuration (Table 3-XI).

Solid/Liquid and Liquid - Several options are available for the liquid/solid concept. With a relatively small solid PKM (Star 37), a medium-size liquid system is required to satisfy Reference Missions B and E. The medium-sized liquid captures a relatively large portion of the spacecraft weight-velocity envelope at medium length and user charge. For a large solid (Star 48/small liquid), the liquid captures a proportionally smaller portion of the envelope at short length and low user charge. Conversely, a large liquid sized to provide Reference Missions B and E coverage covers the entire envelope at the longest liquid length and highest user charge. The trades to determine the most cost-effective system depend on the number of reference missions for each liquid size and liquid/solid size. Some of the stage payload combinations are capable of vertical installation and potentially very low cost based on length.

Based on this rationale, propulsion groups 8 through 14 (Table 3-XI) were synthesized for monopropellant and bipropellent systems as follows:

(a) Small Solid/Medium Liquid
- Group 12 - Star 37/bipropellant

(b) Large Solid/Small Liquid
- Group 8 - Star 48/bipropellant
- Group 9 - Star 48/monopropellant
- Group 10 - Star 48 or MMIII/modular bipropellant
- Group 11 - Star 48 or MMIII/Modular monopropellant

(c) Liquid
- Group 13 - Modular Bipropellant
- Group 14 - Modular Monopropellant

System details and synthesis rationale for these systems are described in Tables 3-XII and 3-XIII.

An example of Liquid Propulsion System Synthesis for capture of all reference missions for Group #10 is shown in Figure 3.4. An eight propellant, eight pressurant tankage configuration sized for Mission B with single AK/PK thruster and single maneuver and nutation control thruster is

TABLE 3-XII SOLID/LIQUID & LIQUID BIPROPELLANT PROPULSION SYSTEM SYNTHESIS RATIONALE

| PROPULSION GROUP | REFERENCE MISSION/CONFIGURATION | SYNTHESIS RATIONALE |
|---|---|---|
| Spinning Star 48/ Liquid Biprop & Liquid Biprop Alone<br><br>Group #8 | B&E - Spinning Star 48/4-Tank Biprop | • Sized for mission B<br>• Spinning Star 48 - offloaded and shortened (size and costs)<br>• 4 propellant tanks for B&E (to limit mission A configuration to 8-tanks with no solid)<br>• Conosphere propellant tanks (minimum length)<br>• Two AK thrusters (minimum length with solid) |
| | A - 8-Tank Biprop | • Configured with maximum number of liquid tanks of mission B size (complexity & handling)<br>• One AK/PK thruster (cost) |
| | C & D - 4-Tank Biprop | • 4 propellant tank mission B liquid alone with offload meets C&D requirements<br>• One AK/PK thruster (cost) |
| Star 37/Liquid Biprop & Liquid Biprop Alone<br><br>Group #12 | B - Star 37/8-Tank Biprop | • Sized for mission B<br>• Liquid alone provides mission A energy requirement<br>• Conosphere propellant tanks (minimum length)<br>• Two AK thrusters (minimum length with solid) |
| | E - Star 37/4-Tank Biprop | • Lower energy mission requires only 4 tanks of mission B size<br>• Two AK thrusters (minimum length with solid) |
| | A - 6-Tank Biprop | • 6 propellant tanks mission B liquid alone with offload meets mission A requirements<br>• One AK/PK thruster (cost) |
| | C & D - 4-Tank Biprop | • 4 propellant tanks mission E liquid alone with offload meets missions C&D requirements<br>• One AK/PK thruster (cost) |

TABLE 3-XII SOLID/LIQUID & LIQUID BIPROPELLANT PROPULSION SYSTEM SYNTHESIS RATIONALE (CONT'D)

| PROPULSION GROUP | REFERENCE MISSION/CONFIGURATION | SYNTHESIS RATIONALE |
|---|---|---|
| Liquid Bipropellant Modular<br>Group #13 | B & E – 8-Tank Bipropellant | • Sized for mission B<br>• 8 propellant tanks maximum (complexity and handling)<br>• Spherical – minimum weight and conospherical – minimum length<br>• One AK/PK thruster (cost)<br>• Propellant offload for mission E |
| | A,C & D – 4-Tank Bipropellant | • Lower energy mission requires only 4 tanks of mission B size with offload<br>• 4 tanks minimize ballast relative to 2 tanks<br>• One AK/PK thruster (cost) |
| Spinning MMIII/ Modular Liquid Bipropellant<br>Group #10 | F – Spinning MMIII/8-Tank Biprop | • Group 13 liquid biprop with Spinning MMIII meets mission F energy requirement |

## TABLE 3-XIII SOLID/LIQUID & LIQUID MONOPROPELLANT PROPULSION SYSTEM SYNTHESIS RATIONALE

| PROPULSION GROUP | REFERENCE MISSION/CONFIGURATION | SYNTHESIS RATIONALE |
|---|---|---|
| Spinning Star 48/ Liquid Monoprop Liquid Monoprop Alone – Group #9 | B – Spin Star 48/4-Tank Monoprop | • Sized for mission B<br>• Spinning Star 48 offloaded & shortened (size and costs)<br>• 4 propellant tanks for B (to limit A config to 8 tanks with no solid)<br>• Conosphere propellant tanks (minimum length)<br>• 4 AK thrusters (min. length and combined RCS) |
| | E – Spin Star 48/2-Tank Monoprop | • Lower energy mission requires only 2 tanks of mission B size<br>• 4 AK thrusters (min length, combined RCS) |
| | A – 8-Tank Monoprop | • Configured with max. no. liquid tanks of B size (complexity) |
| | C – 4-Tank Monoprop | • 4-Tank mission B liquid alone with offloaded provides mission C requirements |
| | D – 3-Tank Monoprop | • Lower energy mission requires only 3 tanks of B size |
| Liquid Monopropellant Modular Group #14 | B – 8-Tank Monopropellant | • Sized for mission B<br>• 8 propellant tanks maximum (complexity and handling)<br>• Spherical – min. weight and conospherical – min. length<br>• 4 AK/PK thrusters (min. length, combined RCS) |
| | A – 4-Tank Monopropellant | • Lower energy mission requires only 4 tanks of mission B size with offload |
| | C & D – 2-Tank Monopropellant | • 2 tanks of mission B size with offload provides missions C and D requirements |

## TABLE 3-XIII SOLID/LIQUID & LIQUID MONOPROPELLANT PROPULSION SYSTEM SYNTHESIS RATIONALE (CONT'D)

| PROPULSION GROUP | REFERENCE MISSION/CONFIGURATION | SYNTHESIS RATIONALE |
|---|---|---|
| Reaction Control System | B - 1 Thruster | • Maneuver and nutation control with favorable inertia ratios |
| | C,D,E,F - 2 Thrusters | • Maneuver and nutation control with unfavorable inertia ratios |
| | A - 4 Thrusters | • Maneuver, stab and control for 3-axis payloads<br>• Biprop stage - common tankage<br>• Monoprop stage - common tankage<br>• Solid Stage - separate reaction control system |

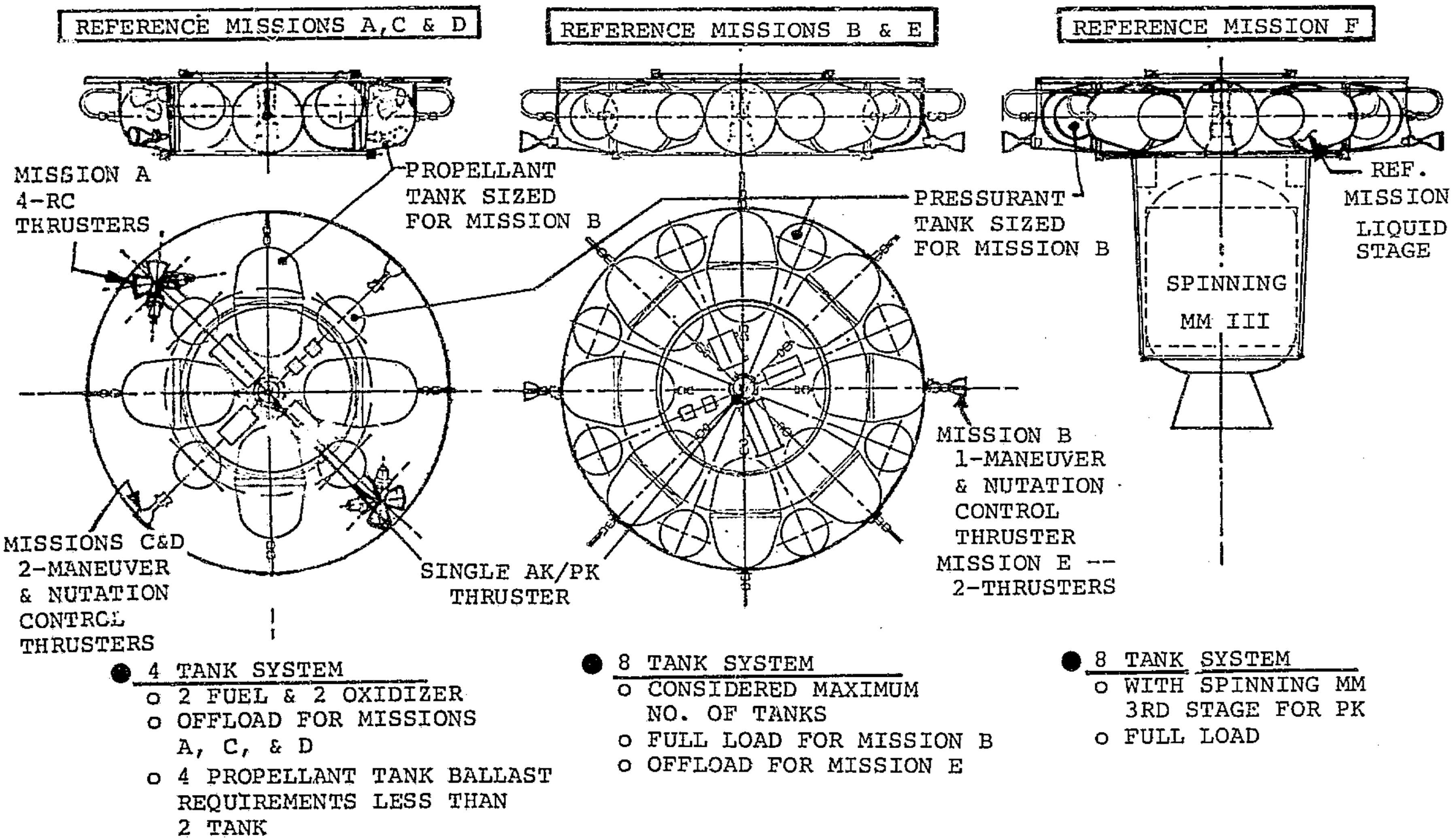



FIGURE 3.4 TYPICAL LIQUID PROPULSION SYSTEM SYNTHESIS
MODULAR BIPROPELLANT

depicted in the middle sketch. To capture Mission E, no changes are made other than offload of propellant and addition of one maneuver/nutation control thruster. As shown in the left sketch, to capture Missions C and D, changes made to the E Mission configuration include removal of four propellant and pressurant tanks and further offload of propellant. The Mission A configuration requires no changes to the Mission C&D configuration except for location of four thrusters into a three-axis arrangement and increased propellant load for the four propellant tanks (left sketch). For Mission F (right sketch), the Spinning MMIII stage is added to the Mission E configuration and a full propellant load is incorporated. Characteristics of the propulsion system hardware common to all configurations and accompanying rationale are:

(a) Conosphere propellant tanks
- Short package length

(b) Common size fuel and oxidizer tanks for each mission
- One propellant tank size reduces cost

(c) Single size pressurant tank, one for each propellant tank
- One size reduces cost

(d) Reaction control tankage common with main tankage
- Minimum cost

(e) Single thruster/configuration
- One thruster for all configurations reduces cost

(f) Single RCS thruster size with quantity and location depending on payload/stage mass properties
- One size reduces cost

(g) Structure modular for all configurations
- One size reduces cost

3.1.2.4 Candidate Liquid Approach Sizing - Velocity requirements, non propulsion subsystem weight data, structural parametric weight relations, and parametric propulsion system weight and performance characteristics were used to determine weights, size and other stage characteristics for synthesized propulsion systems. Typical bipropellant main propulsion system parametric weight as a function of useable propellant weight of an 8 tank bipropellant and 8 tank pressurant tank system with a single main thruster is:

$$W_{PST} = 168 + 1.20\ W_{PU}(\Delta V)$$

where: $W_{PST}$ = Total Main Propulsion System Weight, lbs

$W_{PU}$ = Useable Propellant Weight for $\Delta V$, lbs

Similarly, for an 8 tank monopropellant and 8 tank pressurant tank system with 4 thrusters for velocity change and maneuver/nutation control propulsion system weight is:

$$W_{PST} = 171 + 1.30\ W_{PU}(\Delta V)$$

3.1.2.5 Candidate Solid Approach Sizing

Tandem Solid - With the candidate motors of Table 3-XIV, initial stage inert weight estimates of 145 kg (320 $lb_m$) for the PK motor and 113.4 kg (250 $lb_m$) for the AK motor approaches were developed and evaluated for design and off design mission capture. Selection criteria were as follows:

- $\Delta V$ - The $\Delta V_1$ and $\Delta V_2$ requirements of the mission must be met by the PKM and AKM respectively.
- PK/AK $\Delta V$ Split - The ratio of $\Delta V_1$ to $\Delta V_2$ should permit efficient energy management. Ideally the excess during each burn should be approximately equal.
- Velocity Ratio - The ratio of delivered velocity to required velocity indicates the amount of energy management required. As a target a velocity ratio less than 4 was desired.
- System Length and Weight - Short motor length and light weight were desired for efficient Shuttle integration.

The matrix of motor combinations shown in Figure 3.5 was reduced through screening to meet performance requirements to the most promising motor combinations illustrated in Table 3-XV.

Pintle Nozzle - Propulsion vendor data, modified appropriately for LES motor design requirements, formed the basis for the pintle nozzle design. These data are shown in Table 3-XVI. The Vought estimate differs primarily from Aerojet 1972 data in the duration of the action time. The 100 seconds of burn time is believed to be within the current state-of-the-art, particularly in view of the advances in current carbon-carbon technology.

TABLE 3-XIV CANDIDATE SOLID PROPELLANT MOTORS

| MOTOR | TOTAL IMPULSE n-sec (lbf-sec) | SPECIFIC IMPULSE m/sec (sec) | INITIAL WEIGHT kg (lbm) | BURNOUT WEIGHT kg (lbm) | EXPANSION RATIO | LENGTH cm (in.) |
|---|---|---|---|---|---|---|
| M/M 3rd | 9,256,000 (2,081,000) | 2763 (281.7) | 3564 (7857) | 213 (470) | | 235 (92.5) |
| M/M 3rd (S) | 8,766,000 (1,970,667) | 2616 (266.8) | 3551 (7828) | 200 (441) | | 193 (76) |
| Star 48 | 4,608,000 (1,036,016) | 2864 (292) | 1694 (3734) | 84 (186) | 62.5 | 190 (75) |
| Star 48 (S) | 4,516,000 (1,015,300) | 2807 (286.2) | 1694 (3734) | 84 (186) | 30 | 154 (60.5) |
| Star 37E | 2,911,000 ( 654,400) | 2783 (283.8) | 1122 (2473) | 76 (167) | 30.9 | 168 (66.3) |
| Star 37F | 2,385,000 ( 536,100) | 2803 (285.8) | 913 (2013) | 62 (137) | 41.4 | 151 (59.4) |
| Star 37F (S) | 2,365,000 ( 531,567) | 2779 (283.4) | 912 (2010) | 61 (134) | 30 | 139 (54.8) |
| Star 17A | 318,500 ( 71,600) | 2809 (286.4) | 125 ( 275) | 11.1 (24.4) | 57.9 | 98 (38.6) |
| Star 17A (S) | 310,800 ( 69,880) | 2741 (279.5) | 125 ( 275) | 11.1 (24.4) | 30 | 83 (32.6) |
| Star 26 | 634,800 ( 142,700) | 2662 (271.5) | 261 ( 576) | 31.5 (69.5) | | 84 (33.04) |
| SVM 5 | 793,800 ( 178,450) | 2731 (278.5) | 318 ( 701) | 27.7 (61.1) | 26.8 | 90 (35.53) |
| Star 37S (S) | 1,840,000 ( 413,540) | 2776 (283.1) | 709 (1563) | 46 (102) | 20 | 108 (43.5) |
| Star 37S | 1,870,000 ( 420,430) | 2821 (287.7) | 711 (1567) | 48 (105) | 57.9 | 136 (53.7) |
| Star 17 | 197,900 ( 44,500) | 2807 (286.2) | 79 ( 174) | 8.5 (183) | 60.7 | 69 (27) |
| SVM 2 | 386,500 ( 86,900) | 2754 (280.8) | 159 (350) | 18.5 (40.8) | 28 | 89 (35.0) |
| SVM 4 | 1,825,000 ( 410,280) | 2805 (286.0) | 706 (1557) | 56 (123) | 40 | 153 (60.3) |
| SVM 4 (S) | 1,812,000 ( 407,400) | 2785 (284) | 706 (1557) | 56 (123) | 30 | 137 (54.0) |
| SVM 7 | 1,177,600 ( 264,740) | 2861 (291.7) | 440 (970) | 28.4 (62.6) | 53.25 | 144 (56.9) |
| SVM 7 (S) | 1,163,500 ( 261,563) | 2826 (288.2) | 440 (970) | 28.4 (62.6) | 30 | 115 (45.3) |
| FW 5 | 735,300 ( 165,300) | 2788 (284.0) | 293 (645) | 28.5 (62.9) | 60 | 112 (44.0) |

- Motors marked (S) have been shortened by reducing the expansion ratio to 30:1.
- Except for the M/M 3rd (for which vendor Isp data is available), performance for these shortened motors is an in-house evaluation based on the following assumptions:
  - (a) $C_F$ changes from the value for the existing expansion ratio to the value for 30:1.
  - (b) The effective nozzle half angle does not change.
- Where vendor weight data was not available, it was assumed that the motor weight did not change.

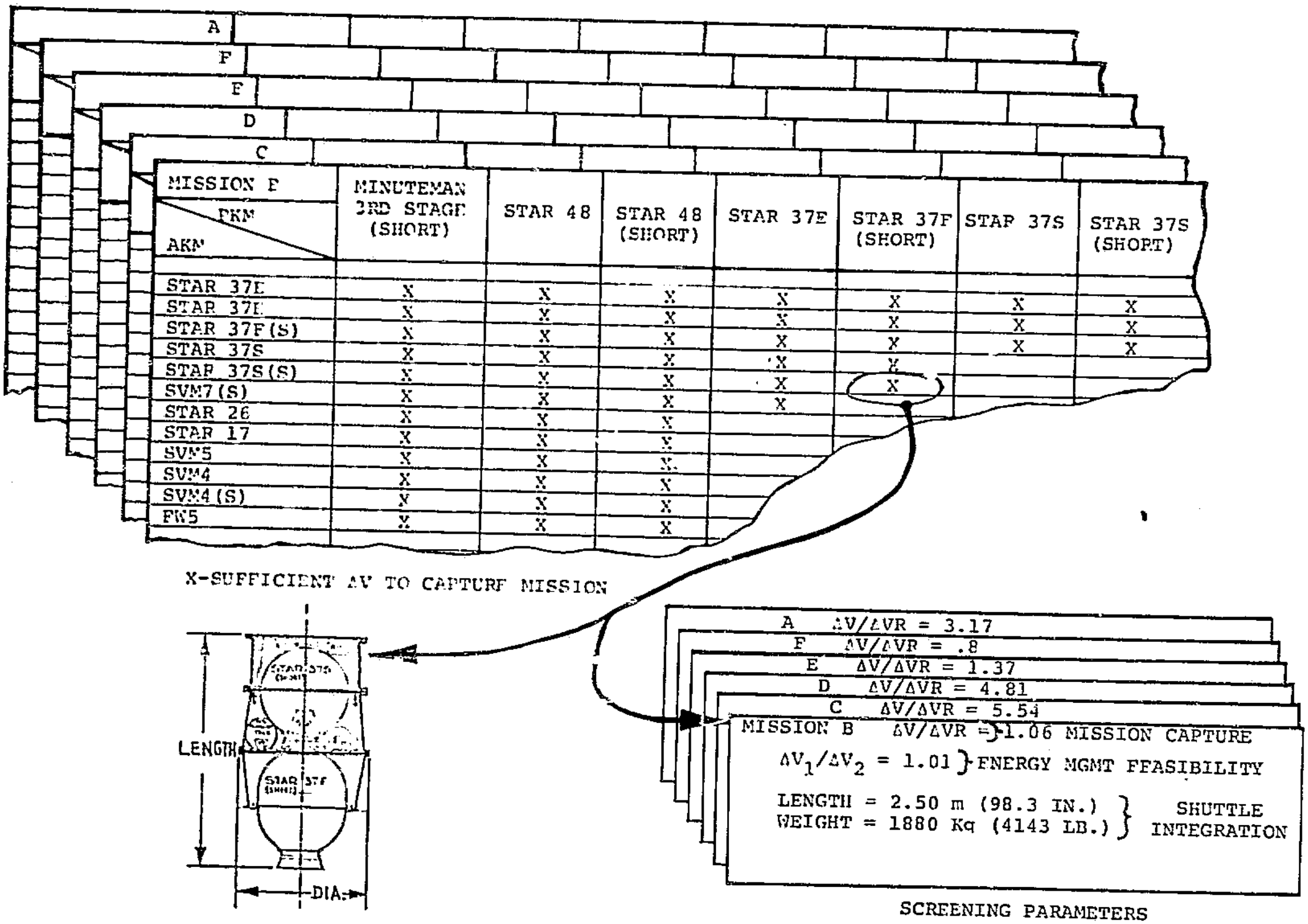



FIGURE 3.5 TANDEM SOLID STAGE SYNTHESIS

TABLE 3-XV SUMMARY OF SOLID PROPULSION APPROACHES

| APPROACH | MOTOR LENGTH CM (IN.) | MOTOR WEIGHT KG (LBM) | ΔV RATIOS FOR REFERENCE MISSIONS A | B | C | D | E | F | DESIGN POINT MISSION |
|---|---|---|---|---|---|---|---|---|---|
| Star 48/Star 37F (short) | 304.8 (120) | 2865 (6317) | 3.58 | 1.57 | 7.60* | 6.01* | 1.70 | 1.00 | F |
| Star 48/Star 37S (short) (short) | 264.7 (104.2) | 2663 (5871) | 4.63* | 1.46 | 7.18* | 5.77* | 1.63 | No[x] | B |
| Star 48/Star 26 (short) | 237.5 ( 93.5) | 2214 (4880) | No[@] | 1.23 | No[@] | 5.01 | 1.42 | No[x] | B |
| Star 37F/Star 37S (short) (short) | 249.7 ( 98.3) | 1882 (4150) | 3.125 | 1.05 | 5.55* | 4.76* | 1.37 | No[x] | B |
| Star 26/Star 26 | 167.6 (66) | 781 (1722) | 1.01 | No[x] | 2.23 | 2.41 | No[x] | No[x] | A |
| Star 17A/Star 17 (short) | 152.4 (60) | 462 (1019) | No[x] | No[x] | 1.0 | 1.20 | No[x] | No[x] | C |

*Exceeds 4.0 velocity ratio requirement

@Poor ΔV split

xInadequate ΔV

## TABLE 3-XVI PINTLE NOZZLE AND LIQUID QUENCH MOTOR CHARACTERISTICS

| PINTLE NOZZLE | AEROJET 1972 PROPOSAL | VOUGHT ESTIMATE |
|---|---|---|
| Thrust | 44,480 n (10,000 $lb_f$) | 44,480 n (10,000 $lb_f$) |
| Total Impulse | $1.112 \times 10^6$ n-sec (250,000 lb-sec) | $4.45 \times 10^6$ n-sec (1,000,000 lb-sec) |
| Impulse Uncertainty | ± 89 n-sec (± 20 lb-sec) | ± 178 n-sec (± 40 lb-sec) |
| Pintle Hardware Weight | 11.4 kg (25.2 lbm) | 22.7 kg (50 lbm) |
| Hydraulic Hardware Weight | 4.0 kg (8.9 lbm) | 6.4 kg (14 lbm) |
| Hydraulic Fluid Weight | 2.4 kg (5.2 lbm) | 2.4 kg (5.2 lbm) |
| Exit Cone Weight | 8.3 kg (18.3 lbm) | 11.3 kg (25 lbm) |
| Duration (at max thrust) | 26 seconds | 100 seconds |
| Expansion Ratio | 30.74 | 30.0 |
| Nozzle length (motor flange to exit cone aft face) | 52.3 cm (20.6 in.) | 52.3 cm (20.6 in.) |
| Nozzle Submerged Length | 13 cm (5 in.)(approx.) | 13 cm (5 in.) |

| LIQUID QUENCH | HERCULES |
|---|---|
| Propellant | 1451 kg (3200 lbs) |
| Case and Insulation | 65.3 kg (144 lbs) |
| Nozzle | 23.1 kg ( 51 lbs) |
| Igniters | 5.4 kg ( 12 lbs) |
| Quench Hardware | 20 kg ( 44 lbs) |
| Quench Fluid | 13.6 kg ( 30 lbs) |
| Miscellaneous | 23.1 kg ( 51 lbs) |
| Inert Weight | 137 kg (302 lbs) + 13.6 kg (30 lbs) quench fluid |
| Total Weight | 1602 kg (3532 lbs) |
| Case Length | 95 cm (37.5 in.) |
| Nozzle Length | 40.4 cm (15.9 in.) |
| Total Length | 135.6 cm (53.4 in.) |
| Isp | 2746 m/sec (280 sec) |
| Stage Weight | 140.6 kg (310 lbs) |
| Case Diameter | 132.1 cm (52 in.) |
| Expansion Ratio | 30:1 |

Case design is based on Vought derived characteristics for a current state-of-the-art design for Reference Mission B. An Isp of 271 sec. was assumed to represent a low aluminum propellant capable of extinguishment at any point in the burn. The resulting motor weighed 1633 kg (3601 lbs.), contained 1497 kg (3300 lbs.) of propellant, had a diameter of 132 cm (52 inches) and was 150 cm (58.9 in.) long. This motor is capable of making all missions (except F) without energy management. However, because of the premium on short length in the Shuttle bay, it could be desirable to develop a smaller motor containing only 590 kg (1300 lbs) of propellant using the same nozzle to minimize development costs. The resulting motor would have a diameter of 94.0 cm (37 in.), be 131 cm (51.6 inch) long and weigh 702 kg (1547 lbs.). It could be used on Missions A, C and D.

Liquid Quench - The liquid quench design, shown in Table 3-XVI, was provided by Hercules. This design is capable of being quenched after 50 percent of the propellant is consumed. It does not include sufficient energy for reference mission F, but would handle missions B and E without energy management. It would, however, require energy management for reference missions A, C and D. Unlike the pintle nozzle, where the nozzle could be made interchangeable, a smaller quench motor would have limited direct commonality with the larger version.

Conventional Clustered Solid - This approach consists of selecting a basic building block motor which will deliver the required velocity for the lowest energy missions (C and D) with the minimum number of motors. Additional motors are then added as required to meet higher energy missions. The minimum number of motors was taken as four, two for AK burn and two for PK burn. The motor selected was the Star 17. Tabulated below are the number of Star 17 motors required, the total velocity increase delivered and the ratio of delivered velocity to required velocity. These

| | MISSIONS | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| Number Star 17 | 7 | 22 | 4 | 4 | 22 |
| ΔV m/sec | 131.6 | 1025.3 | 567.5 | 1343.9 | 3307.4 |
| ΔV (ft/sec) | (432) | (3364) | (1862) | (4409) | (10851) |
| ΔV Delivered/ ΔV Required | 1.10 | 1.025 | 1.42 | 1.5 | 1.0 |

calculated velocities are based on a non-propulsive weight of 340 kg (750 lbs). This may be highly optimistic for a 22 motor cluster. A heavier non-propulsive weight would have little impact on the B mission (because of the heavy payload) but would be critical for the E mission. Because of the relatively poor mass fraction inherent in the cluster approach mission F requirements cannot be set.

Flatpack Clustered Solid - Using constraints and allowances established in prior Vought studies, the following flatpack motor characteristics for reference mission B were derived:

| | |
|---|---|
| Number of Motors | - 6 |
| Grain Length | - 163.8 cm (64.5 in.) |
| Propellant Weight | - 274 kg (604 lbs.) per motor |
| Inert Weight | - 91 kg (201 lbs.) per motor |
| Motor Weight | - 365 kg (805 lbs.) |
| Case Diameter | - 36.8 cm (14.5 in.) |

Due to poor motor mass fraction and high stage inerts, this concept is not capable of meeting reference mission E or F performance requirements. For mission A the same case diameter and nozzle are used but the grain and case length are reduced as required.

| | |
|---|---|
| Number of Motors | - 6 |
| Grain Length | - 45.7 cm (18 in.) |
| Propellant Weight | - 76 kg (168 lbs.) per motor |
| Inert Weight | - 33 kg (72 lbs.) per motor |
| Motor Weight | - 109 kg (240 lbs.) |

When operated as a four motor cluster, the motor sized for mission A produces velocity ratios of 1.42 and 1.36 for missions C and D respectively. Thus, with only two sizes of motors, missions A, B, C, and D could be achieved with a flat pack approach. Alternately, the grains for missions C and D could be cut to size and the missions achieved without energy management.

3.1.2.6 Approach Characteristics - Existing propulsion approaches, adaptations of existing approaches, and new approaches were developed and/or evaluated for each of the reference missions. The approaches for Reference Mission B are shown in Table 3-XVII. Applicability of these approaches to the other reference missions was also determined and can be found in Volume V, Appendix B.

## TABLE 3-XVII PROPULSION APPROACHES FOR REFERENCE MISSION B

| LAUNCH APPROACH | PROPULSION APPROACH | DESCRIPTION: BOOSTER STAGE | DESCRIPTION: DELIVERY STAGE | OTHER MISSIONS CAPTURED | CONFG. NUMBER |
|---|---|---|---|---|---|
| EXISTING APPROACHES | LIQUID | NONE | TRS-4 TANK EXPENDED | NONE | XII |
| ADAPTATIONS OF EXISTING APPROACHES | SOLID/SOLID-TANDEM | SPINNING STAR 48 | STAR 26 | A,C,D,E | 46 |
| | | SPINNING STAR 48 | STAR 37F | E,F | 50 |
| | | SHORT NOZZLE SPINNING STAR 48 | STAR 37-S | A,C,D,E | 1 |
| | | SHORT NOZZLE SPINNING STAR 48 | SHORT NOZZLE STAR 37-F | E,F | 4 |
| | SOLID/LIQUID | SHORT NOZZLE-10% OFF-LOAD SPINNING STAR 48 | 4 TANK BIPROP | E | 15 |
| | | SHORT NOZZLE-10% OFF-LOAD SPINNING STAR 48 | 4 TANK MONOPROP | NONE | 28 |
| NEW APPROACHES | SOLID/SOLID TANDEM | SHORT NOZZLE STAR 37F | SHORT NOZZLE STAR 37F | E | 5 |
| | SOLID/SOLID CLUSTER | NONE | FLAT PACK-6 LONG MOTORS | NONE | 9 |
| | | NONE | 22 STAR 17 MOTORS | E | 38 |
| | CONTROLLED SOLID | NONE | LIQUID QUENCH MOTOR | A,C,D,E | 12 |
| | | NONE | PINTLE SOLID MOTOR | A,C,D,E | 41 |
| | SOLID/LIQUID | STAR 37E | 6 TANK BIPROP | NONE | 19 |
| | LIQUID | NONE | 8 TANK BIPROP | E | 23 |
| | | NONE | 8 TANK MONOPROP | NONE | 33 |

A summary of the physical characteristics and the performance capabilities was prepared for each of the 52 configurations considered. An example of this propulsion approach summary is shown in Figure 3.6 for Reference Mission B (see Volume V, Appendix B, for other candidate propulsion approach summaries). This summary provides a description of the system components together with a definition of the approach used for each subsystem and the basis by which its weight was established. The basis included vendor inputs, weight data on existing or planned subsystems, and Vought experience on similar hardware used in Scout, SCOOP, and SDP, as well as in-house studies such as Small Auxiliary Stages. These data were collected and organized in accordance with a LES work breakdown structure defined in Volume V, Appendix A. Structural arrangements were laid out for each propulsion approach to provide interconnecting load paths between all components, ASE and the payload. Interface structure and separation provisions were provided between the stage and the ASE, the payload and the stage, and between stages where required. The equipment was arranged in a manner to balance the stage for spin stabilization application and to minimize stage length. Figure 3.6 shows an example of the structural and component arrangement for a liquid propulsion approach. In this case, the structure is a combination truss and sandwich construction. The components are mounted to an aluminum sandwich plate which, in turn, is attached to a truss work of aluminum tubing that supports the fuel tanks at each end and provides the interfacing structure with the ASE. A weight summary and performance capabilities in terms of payload weight and velocity increments available relative to each of the Reference Mission requirements are also shown.

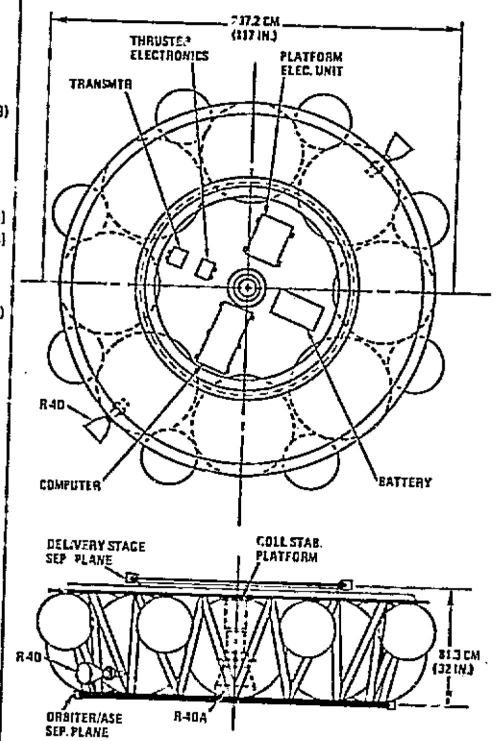
3.1.2.7 Subsystem Components - For costing purposes, subsystem component lists and schematics were developed. As examples, Table 3-XVIII illustrates the main propulsion system components list for propulsion group number 10 and Figure 3.7 presents schematic for a bipropellant main propulsion system.

### 3.1.3 Adaptations of Existing/Planned Approaches

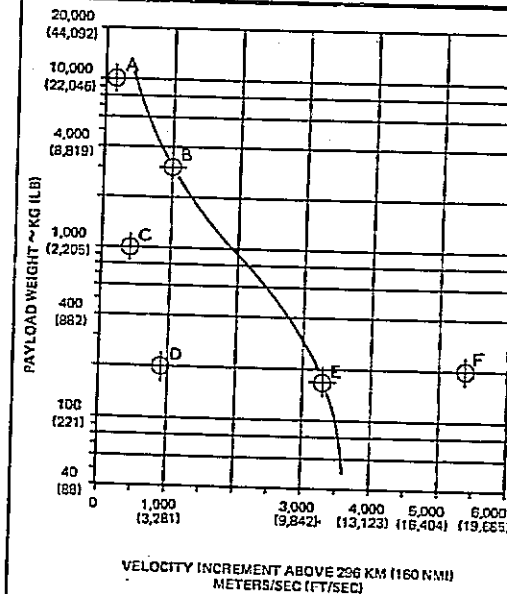
The Spinning Star 48 (SSUS-D) and the Spinning Minuteman III (SSUS-A) were selected as adaptations for Task 2. Because stage descriptions and characteristics were not available from the stage supplier, these stages were baselined as defined in Reference 54. Motor performance, however, was updated through motor supplier inputs. Tables 3-XIX and 3-XX define Spinning

| ITEM COMPONENTS | | |
|---|---|---|
| ITEM | APPROACH/BASIS | WEIGHT, KG ($LB_m$) |
| DELIVERY STAGE | | |
| 0221 INTEGRATION & ASSEMBLY | SEPARATION CLAMP/SCOUT | 7.71 (17) |
| 0222 STRUCTURE | SEMIMONOCOQUE TRUSS/SAS TYPE | 39.01 (86) |
| 0223 THERMAL | SPINNING STAR 48 TYPE | 2.27 (5) |
| 0224 MAIN PROPULSION | BIPROPELLANT ~ 8 SPHERICAL PROPELLANT TANKS & 8 SPHERICAL PRESSURANT TANKS, ONE R-40A THRUSTER/SAS TYPE | 1899.69 (4185.9) |
| *0225 REACTION CONTROL SYSTEM | BIPROPELLANT NUTATION & MANEUVER CONTROL/SCOOP & SAS TYPE | 5.90 (13) |
| 0226 DATA MANAGEMENT/COMM. | S-BAND TRANSMITTER & ANTENNA/SCOUT | 1.5 (3.3) |
| 0227 GUIDANCE & CONTROL | ROLL STABILIZED PLATFORM/SOFT & DOT | 28.26 (62.3) |
| 0228 ELECTRICAL POWER | REMOTELY ACTIVATED SILVER-RING BATTERY & CONVENTIONAL CABLING/SCOUT | 25.85 (57) |
| CONTINGENCY | | 4.76 (10.5) |
| BOOSTER STAGE | | |
| 0201 INTEGRATION & ASSEMBLY | NONE | |
| 0212 STRUCTURE | NONE | |
| 0213 THERMAL | NONE | |
| 0214 MAIN PROPULSION | NONE | |
| 0215 REACTION CONTROL SYSTEM | NONE | |
| 0216 GUIDANCE & CONTROL | NONE | |
| 0217 ELECTRICAL POWER | NONE | |
| CONTINGENCY | NONE | |

CONFIGURATION




PERFORMANCE




WEIGHT SUMMARY

| | | KG | $LB_m$ |
|---|---|---|---|
| DELIVERY STAGE | | | |
| WEIGHT INERT | = | 495.32 | (1092) |
| WEIGHT PROPELLANT | = | 1518.63 | (3348) |
| TOTAL | = | 2013.95 | (4490) |
| BOOSTER STAGE | | | |
| WEIGHT INERT | = | 0 | |
| WEIGHT PROPELLANT | = | 0 | |
| TOTAL | = | 0 | |
| STAGE WEIGHT | = | 2013.95 | |

FIGURE 3.6 PROPULSION APPROACH SUMMARY FOR CONFIGURATION NO. 23

# TABLE 3 XVIII. MAIN PROPULSION SYSTEM

| STAGE | No. | Component | MFGR. | Designation Part/No. | COMPONENT DETAILS WEIGHT kg | COMPONENT DETAILS WEIGHT lbm | Prior Appl. | | B DES. PT. B Quan/Sys. No. | B WEIGHT kg | B WEIGHT lbm | E REF. MISS. E Quan/Sys. No. | E WEIGHT kg | E WEIGHT lbm | A REF. MISS A Quan/Sys. No. | A WEIGHT kg | A WEIGHT lbm | C REF. MISS. C Quan/Sys. No. | C WEIGHT kg | C WEIGHT lbm | D REF. MISS. D Quan/Sys. No. | D WEIGHT kg | D WEIGHT lbm | F REF. MISS. F Quan/Sys. No. | F WEIGHT kg | F WEIGHT lbm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DELIVERY | 1 | Pressure Tank | PSI | 60186-1 | 10.57 | 23.3 | European Prog. | ? | 8 | 84.55 | 186.4 | 8 | 84.55 | 186.4 | 4 | 42.28 | 93.2 | 4 | 42.28 | 93.2 | 4 | 42.28 | 93.2 | 8 | 84.55 | 186.4 |
| | 2 | Pres. Sq. Vlv. | Quantic | 1512-01 | 0.73 | 1.6 | Scoop | Q | 1 | 0.73 | 1.6 | 1 | 0.73 | 1.6 | 1 | 0.73 | 1.6 | 1 | 0.73 | 1.6 | . | 0.73 | 1.6 | 1 | 0.73 | 1.6 |
| | 3 | Orbit Vent Sq Vlv. | Quantic | 1512-01 | 0.73 | 1.6 | Scoop | Q | 1 | 0.73 | 1.6 | 1 | 0.73 | 1.6 | 1 | 0.73 | 1.6 | 1 | 0.73 | 1.6 | 1 | 0.73 | 1.6 | 1 | 0.73 | 1.6 |
| | 4 | Pres Fill & Vent | Purolator | 7542808 | 0.23 | 0.5 | Scoop | Q | 1 | 0.23 | 0.5 | 1 | 0.23 | 0.5 | 1 | 0.73 | 0.5 | 1 | 0.23 | 0.5 | 1 | 0.23 | 0.5 | 1 | 0.23 | 0.5 |
| | 5 | Thrust Neut. | Vought | New | 0.82 | 1.8 | New | – | 1 | 0.82 | 1.8 | 1 | 0.82 | 1.8 | 1 | 0.82 | 1.8 | 1 | 0.82 | 1.8 | 1 | 0.82 | 1.8 | 1 | 0.82 | 1.8 |
| | 6 | Pres. Reg. | Sterer | 40290 | 1.81 | 4.0 | SDP-A | Q | 1 | 1.81 | 4.0 | 1 | 1.81 | 4.0 | 1 | 1.81 | 4.0 | 1 | 1.81 | 4.0 | 1 | 1.81 | 4.0 | 1 | 1.81 | 4.0 |
| | 7 | Check Valve | James P & C. | 6523AUI-10TT | 0.27 | 0.6 | Scoop | Q | 2 | 0.54 | 1.2 | 2 | 0.54 | 1.2 | 2 | 0.54 | 1.2 | 2 | 0.54 | 1.2 | 2 | 0.54 | 1.2 | 2 | 0.54 | 1.2 |
| | 8 | Relief Valve | James P.&C. | 5120T-10TT 4 | 0.77 | 1.7 | Scoop | Q | 2 | 1.54 | 3.4 | 2 | 1.54 | 3.4 | 2 | 1.54 | 3.4 | 2 | 1.54 | 3.4 | 2 | 1.54 | 3.4 | 2 | 1.54 | 3.4 |
| | 9 | Tank Sq Vlv. | Quantic | 1512-01 | 0.73 | 1.6 | Scoop | Q | 16 | 11.61 | 25.6 | 16 | 11.61 | 25.6 | 8 | 5.81 | 12.8 | 8 | 5.81 | 12.8 | 8 | 5.81 | 12.8 | 16 | 11.6 | 25.6 |
| | 10 | Propel Tank | ARDE | None | 22.58 | 43.78 | None | None | 8 | 157.94 | 398.2 | 8 | 180.62 | 389.2 | 4 | 90.32 | 199.12 | 4 | 90.32 | 199.12 | 4 | 90.32 | 199.12 | 8 | 180.62 | 398.2 |
| | 11 | Propel Fill & Drain | Futurecraft | 900287 | 0.14 | 0.3 | Scoop | Q | 16 | 2.18 | 4.8 | 16 | 2.18 | 4.8 | 8 | 1.09 | 2.4 | 8 | 1.09 | 2.4 | 8 | 1.09 | 2.4 | 16 | 2.18 | 4.8 |
| | 12 | Filter | Wintec | 15241-030-1 | 0.59 | 1.3 | Scoop | Q | 16 | 9.43 | 21.8 | 16 | 9.43 | 20.8 | 8 | 4.72 | 10.4 | 8 | 4.72 | 10.4 | 8 | 4.72 | 10.4 | 16 | 9.43 | 20.8 |
| | 13 | Man Dr. Vlv | Futurecraft | 30485-3 | 0.68 | 1.5 | Scoop | Q | 2 | 1.36 | 3.0 | 2 | 1.36 | 3.0 | 2 | 1.36 | 3.0 | 2 | 1.36 | 3.0 | 2 | 1.35 | 3.0 | 2 | 1.36 | 3.0 |
| | 14 | Thruster | Marquardt | R-40A | 9.75 | 21.5 | SSRCT | Q | 1 | 9.75 | 21.5 | 1 | 9.75 | 21.5 | 1 | 9.75 | 21.5 | 1 | 9.75 | 21.5 | 1 | 9.75 | 21.5 | 2 | 19.50 | 43.0 |
| | 15 | Line Set | Vought | None | 2.27 | 5.0 | --- | – | 1 | 2.27 | 5.0 | 1 | 2.27 | 5.0 | 1 | 2.27 | 5.0 | 1 | 2.27 | 5.0 | 1 | 2.27 | 5.0 | 1 | 2.27 | 5.0 |
| | 16 | HE Pres. Xduc. | Teledyn Tabor | 2403-4000-1 | 0.09 | 0.2 | Scoop | Q | 1 | 0.09 | 0.2 | 1 | 0.09 | 0.2 | 1 | 0.09 | 0.2 | 1 | 0.09 | 0.2 | 1 | 0.09 | 0.2 | 1 | 0.09 | 0.2 |
| | 17 | Pr. Pres. Xduc | Teledyne Tabor | 2403 200-1 | 0.09 | 0.2 | Scoop | Q | 1 | 0.09 | 0.2 | 1 | 0.09 | 0.2 | 1 | 0.09 | 0.2 | 1 | 0.09 | 0.2 | 1 | 0.09 | 0.2 | 1 | 0.09 | 0.2 |
| | 18 | Thermister | Stock Item | ---- | 0.05 | 0.1 | Scoop | – | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 |
| | 19 | Thermocouple | Stock Item | I/C | 0.05 | 0.1 | Scoop | – | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 |
| | 20 | Thermocouple | Stock Item | C/A | 0.05 | 0.1 | Scoop | – | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 | 1 | 0.05 | 0.1 |
| | 21 | Cartridges | SOS | NSI 1 | ~ | ~ | Scoop | Q | 36 | | – | 36 | | – | 20 | | – | 20 | | – | 20 | | – | | | – |
| | 22 | Pressurant | ---- | Helium | 7.71 | 17.0 | --- | – | – | 7.78 | 17.16 | – | 7.78 | 17.16 | – | 3.89 | 8.58 | – | 3.89 | 8.58 | – | 3.89 | 8.58 | – | 78 | 17.16 |
| | 23 | Oxidizer | ---- | $N_2O_4$ | | | --- | – | – | 973.8 | 2146.8 | – | 678.9 | 1496.7 | – | 306.3 | 67[illegible] | – | 145.6 | 320.97 | – | 134.1 | 295.69 | | 973.8 | 2146.8 |
| | 24 | Fuel | ---- | MMH | | | --- | – | – | 608.6 | 1341.8 | – | 566.1 | 1248.0 | – | 191.4 | 422.0 | – | 91.0 | 200.61 | – | 383 | 184.8 | | 608.6 | 1341.8 |
| | Propellant Usage Summary | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Propellant Total | | | | | | | | | 1582 | 3489 | | 1472 | 3245 | | 498 | 1097 | | 237 | 522 | | [illegible] | 480 | | 1582 | 3489 |
| | Usage Propellant | | | | | | | | | 1519 | 3348 | | 1408 | 3104 | | 459 | 1012 | | 193 | 436 | | 179 | 395 | | 1519 | 3343 |
| | Total System Weight | | | | | | | | | 1899 | 4186 | | 1788 | 3942 | | 666 | 1468 | | 382 | [illegible] | | 386 | 851 | | 1908 | 4207 |

For all missions the liquid system alone provides the required energy except for mission F which will require a Minuteman III 3rd stage for PKM.

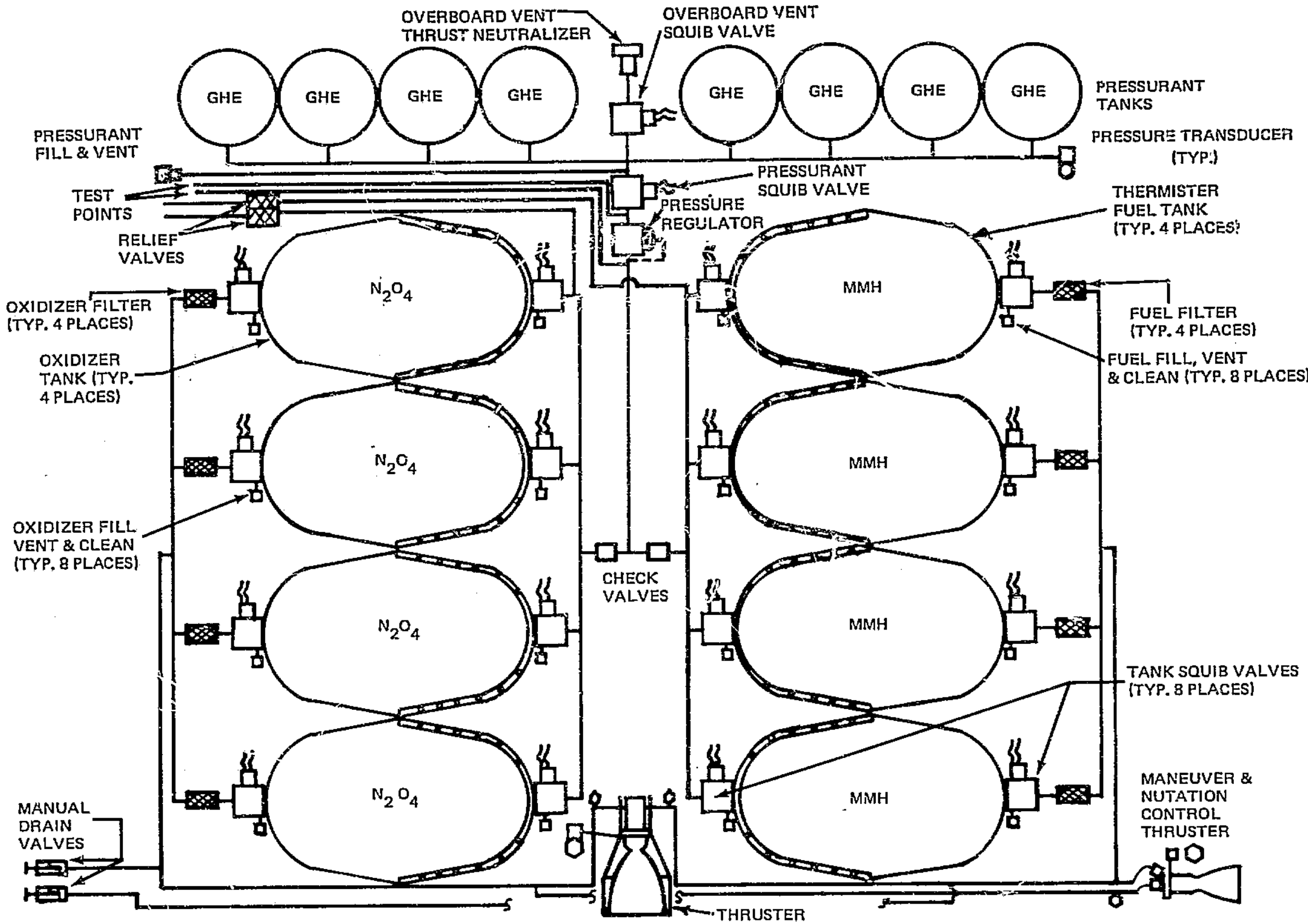



FIGURE 3.7 TYPICAL BIPROPELLANT MAIN PROPULSION AND REACTION CONTROL SYSTEM

TABLE 3-XIX

SPINNING STAR 48 STAGE CHARACTERISTICS (SSUS-D)

| | | | |
|---|---|---|---|
| **MOTOR (FULL LOAD PROPELLANT)** | | | |
| Total Impulse, N-sec ($lb_f$-sec) | | | 4,608,128 (1,036,000) |
| Initial Weight, kg ($lb_m$) | | | 1693.7 (3,734) |
| Burnout Weight, kg ($lb_m$) | | | 84.4 ( 186) |
| Effective Specific Impulse, m/sec ($lb_f$-sec/$lb_m$) | | | 2863.5 ( 292) |
| Total Motor Length, cm (in.) | | | 190.5 ( 75) |
| **STAGE WEIGHTS**, kg ($lb_m$) (10% MOTOR OFFLOADED AND SHORT NOZZLE) | | | |
| Weight at Ignition | | | 1678.8 (3701) |
| Motor Initial Weight | | 1533.6 (3381) | |
| Burnout Weight | 84.4 ( 186) | | |
| Consumed Weight | 1449.2 (3195) | | |
| Separation Clamp | | 7.3 ( 16) | |
| Structure | | 79.4 (175) | |
| Power | | 13.6 ( 30) | |
| Active Nutation Control | | 15.9 ( 35) | |
| Thermal | | 2.3 ( 5) | |
| Destabilization and Spin Balance | | 9.1 ( 20) | |
| Contingency | | 17.7 ( 39) | |
| Motor Length, cm (in.) | | | 153.7 (60.5) |

TABLE 3-XX

SPINNING MINUTEMAN III STAGE CHARACTERISTICS (SSUS-A)

| | | | |
|---|---|---|---|
| **MOTOR** | | | |
| Total Impulse, N-sec ($lb_f$-sec) | | | 9,256,300 (2,081,000) |
| Initial Weight, kg ($lb_m$) | | | 3564.1 (7,857.3) |
| Burnout Weight, kg ($lb_m$) | | | 213.2 (470.1) |
| Effective Specific Impulse, m/sec ($lb_f$-sec/$lb_m$) | | | 2762.5 (281.7) |
| Total Motor Length, cm (in.) | | | 235.0 ( 92.5) |
| **STAGE WEIGHT**, kg ($lb_m$) | | | |
| Weight at Ignition | | | 3751.9 (8271.3) |
| Motor Initial Weight | | 3564.1 (7857.3) | |
| Burnout Weight | 213.2 (470.1) | | |
| Consumed Weight | 3350.8 (7387.2) | | |
| Separation Clamp | | 9.1 ( 20) | |
| Structure | | 124.3 (274) | |
| Power | | 13.6 ( 30) | |
| Active Nutation Control | | 15.9 ( 35) | |
| Thermal | | 2.3 ( 5) | |
| Destabilization and Spin Balance | | 9.1 ( 20) | |
| Contingency | | 13.6 ( 30) | |

Star 48 and Spinning Minuteman III stage characteristics using this rationale. The Spinning Star 48 motor was offloaded 10 percent and the nozzle length was reduced about 36 cm (14.5 in.) to provide vertical installation capability. These two stages were considered as perigee burn stages in conjunction with solid and both bipropellant and monopropellant liquid upper stages to develop the adaptations of existing approaches considered.

## 3.2 SCREENING METHODOLOGY

The screening in Task 2 was limited to new and adaptation concepts with final screening (comparing new and existing) being performed in Task 6 (Volume IV). The concept screening sequence was as follows:

(1) Derive the costs of the candidate new and adaptations launch approaches.

(2) Perform a preliminary screening of the candidate new launch approaches against the launch cost envelope and eliminate those that indicate user costs significantly higher than the existing/planned approaches.

(3) Stack the remaining launch approaches in increasing order of cost for each reference mission.

(4) Finally screen these remaining launch approaches by comparing different launch approach combinations for the combined reference missions to find several combination of approaches to launch all reference missions at low cost.

(5) From the final screening, select three or four new or adaptations to existing/planned launch approaches that will continue into subsequent tasks.

### 3.2.1 User Costs

Vehicle recurring costs were combined with the Shuttle user charge for both stage and payload to make up the total user cost for the screening sequence. For each new candidate approach selected in screening sequence (3), LES vehicle costs were collected against the work breakdown structure (WBS) defined in Volume V, Appendix A for (1) project management and systems engineering and integration to level 4; (2) the LES vehicle to level 5; and (3) Shuttle user charge to level 3 for stage and ASE. For adaptations to existing/planned approaches, the WBS level of cost collection was the same as for a new approach except that for LES vehicle costs the level and scope

depended on the modifications to be made. Costs were based on a production rate of 10 units per year for screening sequences (1) through (3). For the final screening of sequence (4), the production useage was launch-combination dependent and the costs adjusted accordingly. Development costs for the LES vehicle were derived for the launch concepts selected for the final screening in step (4).

The Shuttle user charge was determined as shown in Table 3-XXI. User charges for payload are included in the cost analysis since for length-critical, vertical installations with payload diameter less than stage diameter the total charge is based on the greatest length of the payload/stage combination.

3.2.2 Preliminary Screening

A preliminary screening of the candidate launch approaches against the launch cost envelopes described in paragraph 2.4 was performed. Launch approaches were selected for additional screening that reflected user cost not significantly above the lowest existing/planned approaches.

3.2.3 Screening By Reference Mission

Using the format of Table 3-XXII, the user costs for each reference mission were stacked in order of increasing cost. The table shows the secondary considerations to be addressed when costs are essentially equal for competing launch approaches.

3.2.4 Screening Methodology for Combinations of Approaches

The methodology used to select three or four of the lowest cost combinations of propulsion approaches, to launch all reference missions, is shown in Figure 3.8. A series of logical combinations that have potential for low cost were selected from the propulsion approach cost ranking by reference mission. Stage unit cost for each propulsion approach in each selected combination was adjusted for the quantities required. Unit costs were based on a twenty quantity buy every two years for an average usage of ten per year. The usage in the various combinations can vary depending upon the number of reference missions captured by a particular propulsion approach. The adjusted unit cost for each stage configuration was multiplied by the number of payloads for each stage configuration and summed. The Shuttle user charge (for stag ASE and payload) for each configuration and reference mission was multiplied by the number of payloads in each reference mission and summed.

Other costs of stage and ASE development and program maintenance were added to the launch costs to provide the total program cost for each combination of approaches. The stage development costs include subsystem

## TABLE 3–XXI SHUTTLE USER CHARGE

$$\text{USER CHARGE} = \frac{\text{LOAD FACTOR}}{0.75} \times \text{SHUTTLE CHARGE}$$

- LOAD FACTOR IS THE GREATER VALUE, DETERMINED BY:
  - – VEHICLE LENGTH ÷ 60 FT., OR
  - – LAUNCH WEIGHT ÷ ALLOWABLE WEIGHT (FOUR ORBIT INCLINATIONS)
- PRICE OF DEDICATED STS FLIGHT TO CIVIL GOVERNMENT USERS – \$18M IN FY 1975 \$
- SHUTTLE CHARGE ADJUSTED TO MID FY '77 DOLLARS USING BUREAU OF LABOR STATISTICS INDEX FOR COMPENSATION PER HOUR, TOTAL PRIVATE.
- SHUTTLE CHARGE USED IN STUDY – \$21.834 MILLION
- EXAMPLES:
  - – LENGTH FACTOR: \$485,000 PER FOOT FOR GOVERNMENT USERS
  - – WEIGHT FACTOR: \$488 PER POUND – ETR $28.5^0$ LAUNCH
    \$787 PER POUND – WTR POLAR LAUNCH

TABLE 3-XXII

LAUNCH APPROACH AND REFERENCE MISSION
SCREENING FORMAT

| REFERENCE MISSION C | |
|---|---|
| LAUNCH APPROACH | USERS COST (MISSIONS) |
| SMALL LIQUID BIPROPELLANT | 3.1 |
| SPINNING STAR 48 WITH A SMALL SOLID AKM | 5.7 |

SECONDARY CONSIDERATIONS

1. PERCENT OF REFERENCE MISSION CAPTURED
2. RELATIVE ACCURACY COMPARISON
3. RELATIVE RISK COMPARISON

- OBJECTIVE: Determine three or four of the lowest cost combinations of approaches that capture all reference missions

- APPROACH:

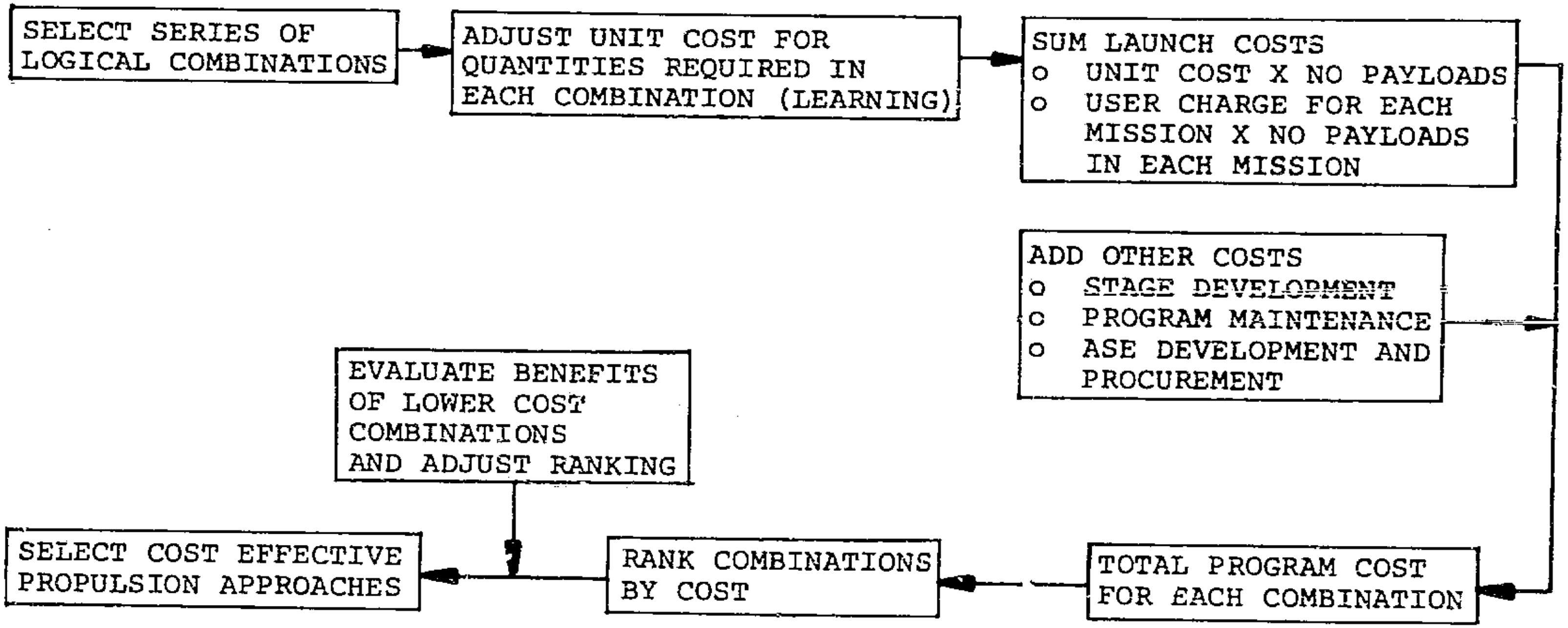



FIGURE 3.8 SCREENING METHODOLOGY

development, integration and assembly, system engineering and integration and software. The ASE development costs in lude development and the procurement of three sets. The program maintenance costs include sustaining and operations costs necessary to conduct an on-going program. Not included in the unit or development costs are flight operations, ground support equipment, and facilities. These costs were not expected to be significantly different for different propulsion approaches and thus would not influence the screening and selection of the lower cost propulsion approaches. The "launch costs" and the "other costs" were summed to provide the total program cost for each combination of approaches.

The combinations of approaches were ranked in order of increasing cost. Mission capture, accuracy and risk (elements of benefits evaluation of the lower cost combinations) were evaluated and where costs were essentially equal the ranking was adjusted. Propulsion approaches for continuing detailed analysis were selected from the adjusted ranking.

### 3.2.5 Benefits Evaluation

In the screening process, if cost benefits were essentially equal between launch approaches, other considerations of mission capture, mission accuracy and risk were used as resolution criteria. These other benefits were rated on a 10 to 0 score (with 10 high) for each reference mission and summed to give a total benefit rating for equal cost launch approaches. Mission capture, mission accuracy, and risk were given equal weight in the total benefit rating since it is important that a low rating in any one of these be reflected in the total. Mission capture is a measure of the capability of a launch approach to capture the low energy regime. Mission accuracy is a measure of how well a launch approach accomplishes each mission and reflects penalties relative to excessive energy management (yaw steering) and attendant delivery inaccuracy. Risk was defined as a measure of new technology and new hardware development. A need for development testing of a new propellant was classified as new technology development. A need for the qualification of a new guidance system using existing technology was classified as new hardware development. A low mission capture directly affects the benefit value of a launch approach as does the mission planning constraints and delivery inaccuracy associated with the wasting of large amounts of energy.

Similarly, a launch approach with a high degree of risk associated with new technology and new hardware development directly affects the benefit value of that approach.

3.2.5.1 Mission Capture Benefit Rating - The energy requirements of the low energy regime are very broad and are reflected in the reference mission payload requirements. For example, the energy for reference mission F is 41 times that of reference mission A. The greater the portion of the energy regime that can be captured by a single launch approach the greater the potential for reducing the number of launch approaches. A high capture reduces development costs, unit costs, operational costs, logistics, and improves reliability. While the costs associated with most of these items ar reflected to a degree in the costs of the launch approaches being considered, the reduction in the number of launch approaches is of such importance that it deserves a separate rating. The mission capture benefit rating, based on velocity change capability, is the percent of the reference missions captured divided by 10.

Mission Capture Benefit Rating = % of Missions Captured ÷ 10

3.2.5.2 Mission Accuracy Benefit Rating - A high capture rating may require inefficient performance from some launch approaches. For example, a fixed impulse solid/solid launch approach designed to capture high energy missions requires peculiar mission planning such as yaw steering or ballasting when used in a low energy application. Ballasting to reduce the amount of yaw steering is not a desirable solution, as approximately 50 percent of the launches are from WTR where weight is predominant in the Shuttle user charge. For a controllable solid or liquid approach, no peculiar mission planning is required. The energy wasting/mission planning peculiar to the fixed impulse launch approach reflects itself primarily in orbit destination error. Analysis has revealed that orbit accuracy degrades significantly for fixed impulse launch approaches when the ratio of wasted energy to the energy required is 3.0. The accuracy rating equation is designed to produce a rating of 1 when the ratio of wasted energy to energy required is 3.0. Additionally each accuracy degrading characteristic such as multi-motor thrust alignment is assumed to penalize the accuracy rating one point.

$$\text{Mission Accuracy Benefit Rating} = 10 - 3\,\frac{\Delta V_{wasted}}{\Delta V_{required}} - \begin{array}{c}\text{Number of}\\ \text{Accuracy}\\ \text{Degrading}\\ \text{Characteristics}\end{array}$$

3.2.5.3 Risk Benefit Rating - A primary objective of the study was to use production hardware components that have demonstrated their performance in actual space flight. When this objective is met, there exists the need to combine existing production components in a different manner, to require increased or decreased size, to use a component in a different application, or to upgrade component performance. An example is the SOFT Program attitude control platform that was used in a spinning application to maintain attitude reference for attitude control after despin. This platform has potential for a spinning low energy stage, but its use would be as an attitude reference to change vehicle attitude while the vehicle is spinning. No modifications to the SOFT platform are required; however, its usage and interfacing components will be different. There is a degree of risk associated with this different usage application and it was accounted for in the risk benefit rating by the subtraction of points for each major subsystem that contains such changes that lead to hardware development testing.

There are some candidate propulsion modes that involve new technology development. An example of this is the water quench controllable solid. A new propellant grain compatible with manned spacecraft operation (Class 2 propellant) would have to be proven. Neither the propellant subsystem or the rocket motor system have been proven in space flight. The risk associated with this new technology development was accounted for in the risk benefit rating by subtracting one rating point for the unproven subsystem (the propellant grain) and one point for the total system which is also unproven. Using the water quench controllable solid as a sample case, the number of subsystems requiring development testing are: (1) propellant (technology development); (2) water quench (hardware development); (3) low L/D case (hardware development); (4) guidance and control (hardware development); and (5) system performance (technology development). In this sample case the risk benefit rating is 10 - 5 = 5.

$$\text{Risk Benefit Rating} = 10 - \left\{ \begin{matrix} \text{Number of New} \\ \text{Technologies} \\ \text{Development} \end{matrix} + \begin{matrix} \text{Number of New} \\ \text{Hardware} \\ \text{Development} \end{matrix} \right\}$$

## 3.3 COST OF CANDIDATE NEW APPROACHES

In order to compare the array of propulsion approaches quickly with appropriate accuracy a mechanized cost evaluation methodology was used, with the necessary flexibility and attention to detail, to clearly reflect system differences. The costing methodology utilized a work breakdown structure (WBS) developed quite early in the LES study to assure consistent definition of propulsion system approaches, together with a complete summarization of configuration design differences to the subsystem level. The basic cost information used in the costing exercise included internal (company historic) cost data, vendor quotations, and other published report data. Solicitation of vendor quotations was necessary to more accurately measure the unique differences of competing designs, and to check the accuracy of cost records used in the study. The costing methodology utilized a special checking feature, where input data could be evaluated relative to existing cost models by means of developed complexity factors. By use of this feature, the relevence of cost data could be checked before use and verified for accuracy and commonality of costing assumptions.

### 3.3.1 Cost Evaluation Methodology

Costs were derived using a computerized parametric cost modeling methodology. This technique, known as the RCA PRICE (Programmed Review of Information for Costing and Evaluation) system, provides reliable estimates of system acquisition costs (development and production) during the conceptual phase of a system development program. Its use permits rapid and timely cost evaluations, based on variations in designs, performance schedules, reliability, economic escalations, etc. Since all estimates involve comparative evaluation of new requirements to analogous histories, irregardless of the estimating technique used, it is necessary to classify a new design in such parameters that it may be related to available basic data. The costing methodology utilizes configuration definitions which are primarily the physical characteristics of the design concept. These include size, weight,

type of componentry, component count, material type, power dissipation and construction type, as well as prototype and production quantities. In addition the methodology is sensitive to design and production schedule, learning (progress) curve, integration characteristics, design and manufacturing complexity, design redundancy, the degree of new design required, and fabrication method. One mode of this cost estimation methodology produces a estimation of design, manufacturing and producibility complexity from physical, schedule and cost data. This mode was used in the cost exercise where the design being costed was of a unique nature with limited relationship to historical data. Vendor quotations were processed through this mode to establish credibility. Where complexity factors appeared inconsistent with historical data the credibility of the costs were questioned. In such cases, further evaluation was required before adjusted costs were used. The final step in the costing methodology was the review of subsystem costs by technical and cost specialists for consistency among similar subsystems on different propulsion approaches. The costing sequence for a typical propulsion approach is shown on Figure 3.9. Subsystems are costed independently, then combined to develop delivery stage or booster cost, which are again combined to develop the cost of a propulsion approach.

### 3.3.2 Costing Assumptions

Because of the low level of LES usage, it was considered advisable to establish special production guidelines which would fit this condition. Production was spread over a total 10-12 year period and the quantity of procured items was set at the total number required for use during that period for mission requirements. A production cycle was established to produce a two-year usage quantity, then production was assumed interrupted until the next production quantity was placed on order. Some learning takes place for any effort spread out over an extended time period. The effects of "learning" are well established in manufacturing industry. However, when a production run is interrupted, some of the "learning" and associated cost effectiveness is lost. When production begins again, some trained personnel have left or have been reassigned, some tools are lost, etc., thus the learning curve applicable to the next production run is not simply a continuation of the learning curve of the prior run. The loss of "learning" as that production

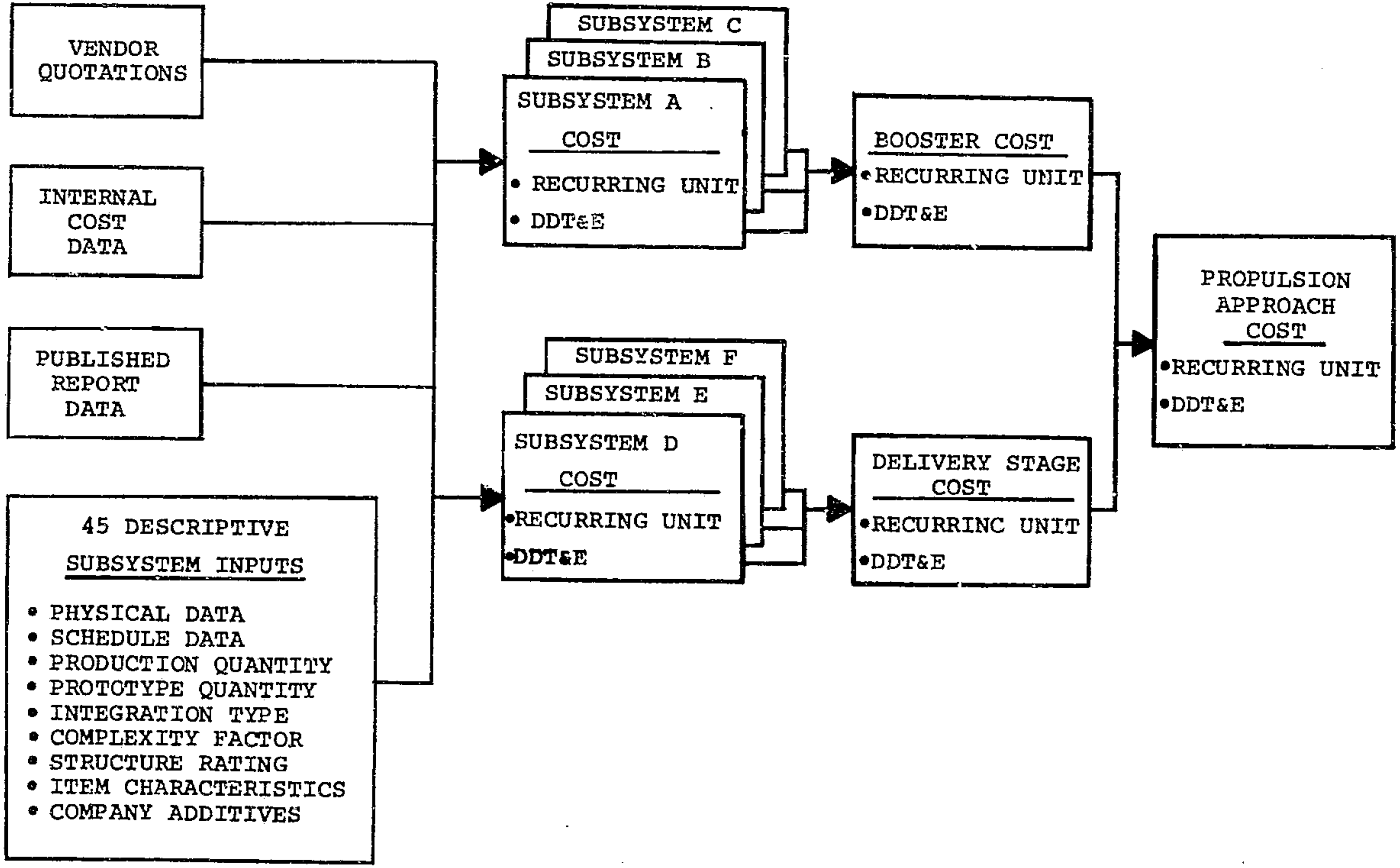



FIGURE 3.9 PROPULSION APPROACH COSTING METHODOLOGY

restarts at a point higher up on the learning curve. Figure 3.10 illustrates the interrupted production situation. To compensate for loss of "learning" for interrupted production schedules, the empirical data set for the second run must be adjusted. The longer the production interruption, the less residual learning remains until a final limit is reached. To determine the probable learning curve which would apply to the LES production program, a trade study was conducted. A structural item was selected for study since it was considered to be highly labor intensive and subject to maximum learning impact. For a typical production quantity of 103 structural units, produced without regard to production need, the optimum learning curve was determined to be 0.898 (89.8%), for a program length of nineteen (19) months. Production rate was approximately 5.42 units per month. When production quantity was cut to 20-21 items per run, for five independent production periods during the ten (10) year period, the rate of composite learning drops to approximately 0.941 (94%). A selection of material intensive subsystem items showed increase from the normal 92% range to the 95% learning regime, hence this value was selected as most applicable to the LES system. All subsystems were estimated for 103 item cumulative average quantity and five equivalent lots of production. For variances in total production quantity, the 95% Wright slope was assumed applicable. DDT&E costs were developed for a modular family of vehicles of each type studied. For combinations of vehicles, requiring more than one type, the development cost was integrated by consideration of the existing commonality between differing types. All costs were developed in 1977 calendar year dollars.

### 3.3.3 Cost Development - LES Vehicle

Production costs were developed for each configuration in the study. Several configurations of a similar type may be grouped to form a modular family. DDT&E costs were developed to take advantage of the cost commonality that exists to a large extent between these vehicles.

3.3.3.1 Production Costs - A summary of production costs for a Star 48/6 tank bipropellant solid/liquid tandem propulsion approach is shown in Table 3-XXIII. Costs for 20 units per lot are detailed for each subsystem for both booster and delivery stages as defined by the work breakdown structure.

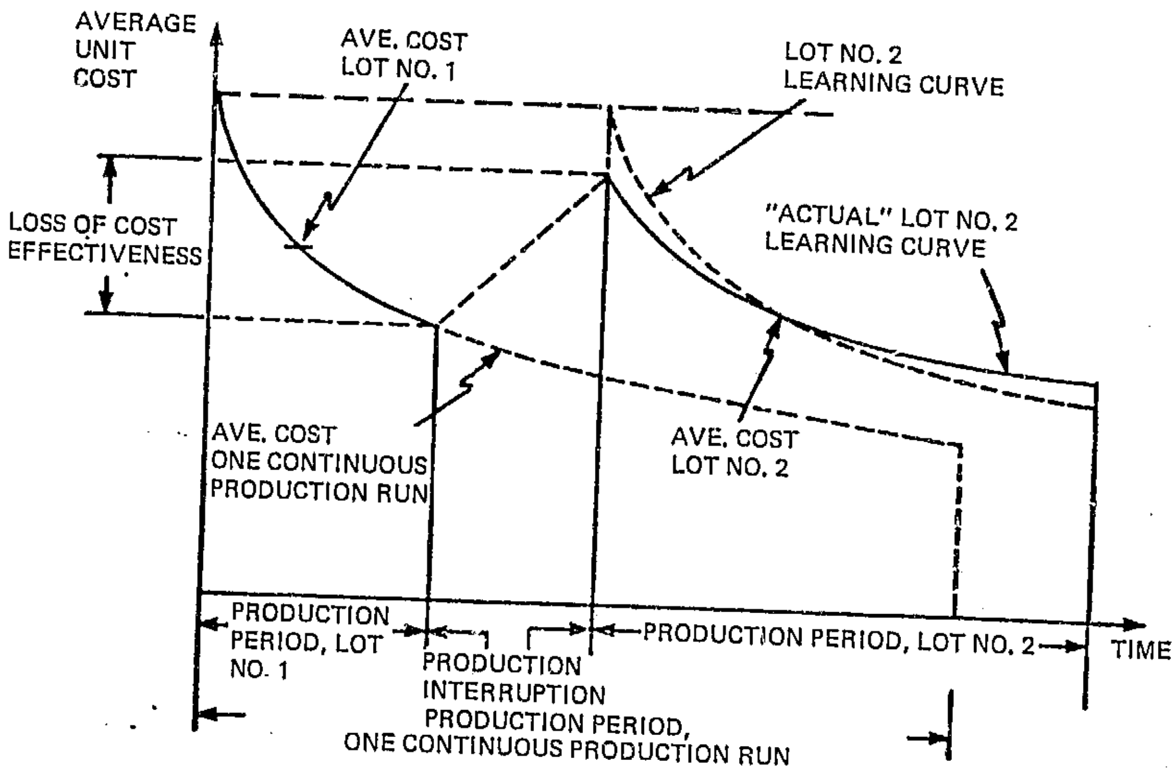



FIGURE 3.10 LOSS OF LEARNING DUE TO INTERRUPTED PRODUCTION

## TABLE 3-XXIII TYPICAL PRODUCTION COST SUMMARY

THOUSANDS OF DOLLARS

Solid/Liquid Tandem Propulsion Approach

Star 37E/6 Tank Bipropellant

| ITEM | Delivery Stage - 20 Units WBS ELEMENT | Delivery Stage - 20 Units COST | Booster - 20 Units WBS ELEMENT | Booster - 20 Units COST |
|---|---|---|---|---|
| Subtotal | 10-0220 | ($22,439) | 10-0210 | ($ 7,879 ) |
| Integration & Assembly | 10-0221 | 1,114 | 10-0211 | 223 |
| Structure | 10-0222 | 990 | 10-0212 | 737 |
| Thermal | 10-0223 | 6 | 10-0213 | 6 |
| Main Propulsion | 10-0224 | 11,173 | 10-0214 | 6,913 |
| RCS | 10-0225 | 1,145 | 10-0215 | --- |
| Data Mgt/Comm | 10-0226 | 367 | 10-0217 | --- |
| GN&C | 10-0227 | 7,264 | --- | --- |
| Electrical Power | 10-0228 | 380 | 10-0218 | --- |
| Integration & Assembly - Subtotal | | | 10-0201 | ($ 679 ) |
| Total Production - 20 Units | | | 10-0200 | $30,997 |
| Total Production Cost/Vehicle | | | 10-0200 | $ 1,549.9 |
| User Charge Cost/Vehicle and Payload (Reference Mission B Payload) | | | 20-0100 | $17,620 |

The costs are accumulated for each stage and finally for the complete propulsion approach. Adjustments for quantity variation were made.

3.3.3.2 DDT&E Costs - A summary of development (DDT&E) costs for a modular liquid monopropellant propulsion approach is shown in Table 3-XXIV. Costs are shown for each subsystem as defined by the work breakdown structure and are summed for the modular stage. The noted example requires no independent booster and the main propulsion thrusters are modulated for attitude control of the stage, thus requiring no separate reaction control subsystem.

### 3.3.4 Cost Development - ASE

Cost information used in the development of Airborne Support Equipment (ASE) costs included available costs on two spinning upper stages, the Inertial Upper Stage, and the Multimission Modular Spacecraft, as well as cost data developed in Vought internal studies. This cost data along with selected measurable descriptive data provided the necessary inputs for a complexity assessment utilizing the mechanized cost evaluation methodology. The resulting complexity factors, which define engineering, manufacturing and producibility complexity, were compared to published system tabular data and Vought cost data to verify the validity, applicability and consistency of ASE costs.

Based on these comparisons, specific complexity factors were established and along with ASE description data (such as weight, volume, quantity, and learning curve) used to compute both development and recurring costs for ASE. The sequence of events is shown on Figure 3.11. The ASE costs include development and the procurement cost of three units - one for each launch site and one spare.

### 3.3.5 Cost Development - Program Maintenance Costs

The program maintenance costs shown in Table 3-XXV are the sustaining and operations costs necessary to conduct an on-going program. These costs were estimated using the NASA Scout program cost experience as the baseline reference weighted with the LES/Scout comparative complexity. The sustaining costs shown include NASA and contractor project management, reliability and training, sustaining engineering, and spares and logistics administration.

The operations costs consist of both unit and annual costs. The unit operations costs shown are those that are unique to each LES/payload

# TABLE 3-XXIV TYPICAL DDT&E COST SUMMARY

THOUSANDS OF DOLLARS

MODULAR LIQUID PROPULSION APPROACH

| WBS ELEMENT | ITEM | DDT&E COST |
|---|---|---|
| 10-0220 | Delivery Stage - Subtotal | ($ 16,311) |
| 10-0221 | Integration & Assembly - Del. Stage | 2,093 |
| 10-0222 | Structure - Delivery Stage | 583 |
| 10-0223 | Thermal - Delivery Stage | 83 |
| 10-0224 | Main Propulsion - Delivery Stage | 6,128 |
| 10-0225 | RCS - Delivery Stage | --- |
| 10-0226 | Data Mgt/Comm - Del. Stage | 181 |
| 10-0227 | GN&C - Delivery Stage | 6,494 |
| 10-0228 | Electrical Power - Del. Stage | 749 |
| 10-0200 | Total Development Cost | $ 16,311 |

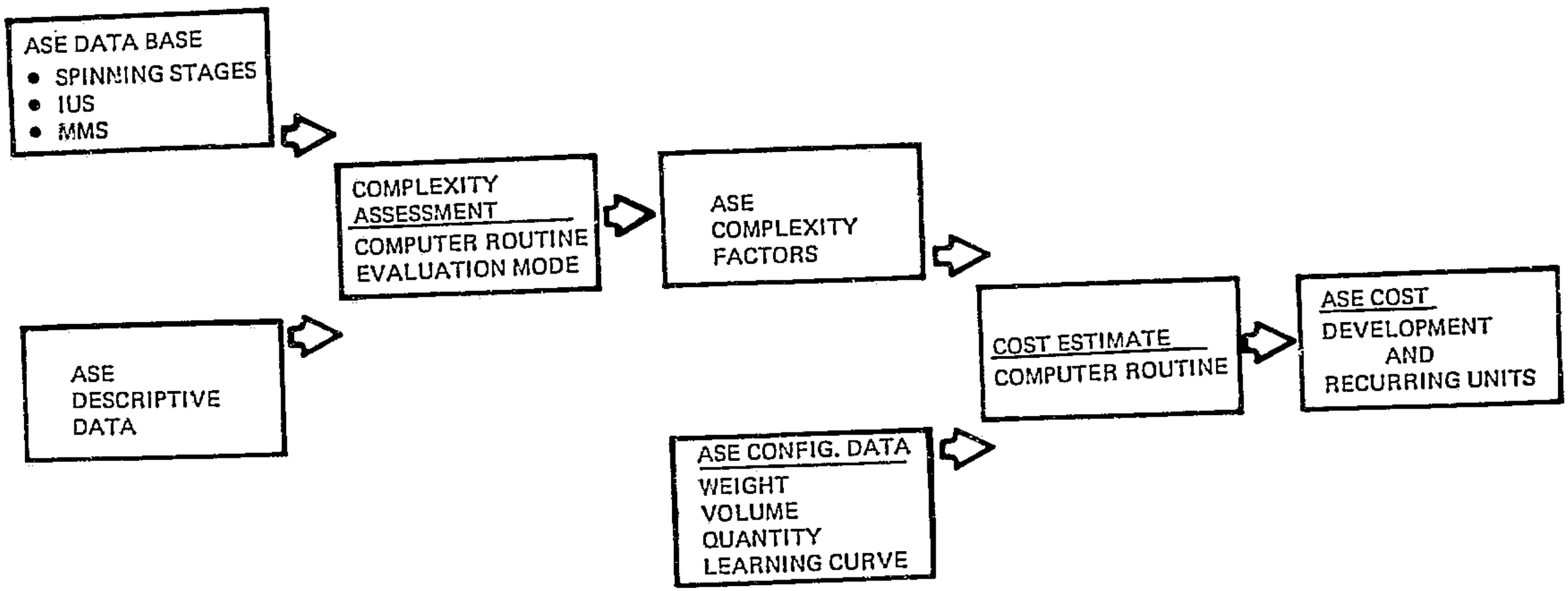



FIGURE 3.11 ASE COSTING METHODOLOGY

## TABLE 3-XXV PROGRAM MAINTENANCE COSTS

| WBS ELEMENT | ITEM | SUSTAINING COSTS ANNUAL | OPERATION COSTS UNIT | OPERATION COSTS ANNUAL |
|---|---|---|---|---|
| 10-0100 | PROJECT MANAGEMENT | | | |
| | NASA MANAGEMENT | 362,500 | | |
| | CONTRACTORS PROJECT MGMT. (12 PEOPLE) | 600,000 | | |
| 10-0400 | SYSTEM ENGINEERING AND INTEGRATION | | | |
| -0401 | CONFIGURATION CONTROL | | 61,500 | |
| -0401 | RELIABILITY AND TRAINING | 371,000 | | |
| -0401 | PREFLIGHT PLANNING | | 15,000 | |
| -0401 | DATA REDUCTION | | 33,000 | |
| -0402 | ASE INTEGRATION | | 17,000 | |
| -0403 | PAYLOAD INTEGRATION | | 17,000 | |
| -0404 | SUSTAINING ENGINEERING (6 ENGINEERS) | 300,000 | | |
| 20-020 | ORBITER INTEGRATION | | 18,000 | |
| 10-0900 | GROUND OPERATIONS | | | |
| -0902 | SPARES & LOGISTICS ADMINISTRATION (3 PEOPLE) | 140,000 | | |
| -0903 | ETR LAUNCH CREW (18 PEOPLE 1980 ACTIVATION) | | | 617,500 |
| -0903 | WTR LAUNCH CREW (18 PEOPLE 1983 ACTIVATION) | | | 617,500 |
| -0903 | RANGE SERVICES (T/M, COMM., FACILITIES, ETC.) | | 90,000 | |
| -0903 | LAUNCH SUPPORT, LES CONTRACTOR (30 MAN-DAYS) | | 6,000 | |
| | TOTAL ANNUAL SUSTAINING COSTS ① | 1,773,500 | | |
| | TOTAL UNIT OPERATIONS COSTS | | 257,500 | |
| | TOTAL ANNUAL OPERATIONS COSTS ② | | | |
| | PRIOR TO 1983 | | | 617,500 |
| | AFTER 1983 | | | 1,235,000 |

NOTE: ① EACH LES CONFIGURATION CARRIES THE TOTAL ANNUAL SUSTAINING COST.

② ANNUAL OPERATIONS COSTS FOR THE STS LOW ENERGY REGIME.

combination. The annual operations costs are those costs required to maintain a full time launch crew at ETR beginning in 1980 and a full time launch crew at WTR beginning in 1983. These two launch crews will provide all operations support required for all low energy stages.

## 3.4 COST/SCREENING ANALYSIS

The user costs for screening were built up in accord with the procedure described in paragraph 3.2. A typical example of the user cost buildup is shown in Table 3-XXVI. The user cost buildup for all the new propulsion approaches investigated are shown in Appendix B, Volume V. Stage weight was based on a buildup of the subsystem and integration weights as defined by the work breakdown structure. The ASE weight was based on an empirically derived equation, ASE weight = .151 (stage weight) + 505 kg. This equation was derived from existing/planned Shuttle upper stage ASE weights and detail ASE weight studies. Launch weight is the sum of the stage weight, ASE weight and payload weight.

For vertical installation, the cargo bay length required was determined by the stage or payload diameter whichever was greater. For horizontal installations the cargo bay length required was determined by the length of the stage plus the length of the payload. Each stage and payload combination was evaluated against the constraints of the cargo bay to determine if vertical installation could be accommodated. If a vertical installation was possible, both horizontal and vertical installations were evaluated and the lower user cost selected for comparison to other propulsion approaches. In this example only the horizontal installation was possible. For purposes of propulsion approach screening, the ASE was considered to be within the length of bay occupied by the stage and payload, thus no extra bay length charge was accumulated. The length load factor was greater than the weight load factor for this example; therefore, the Shuttle charge was based on the length of the stage and payload.

Unit cost was derived as a buildup of the subsystem costs shown in the work breakdown structure. The total user cost for comparison at the reference mission level was the Shuttle charge plus the stage unit cost.

### 3.4.1 Screening by Reference Mission

Table 3-XXVII shows a summary of the cost to launch the payload of each reference mission using each of the propulsion approaches considered. Propulsion approaches are ranked in increasing cost order for all new and

## TABLE 3-XXVI TYPICAL PROPULSION APPROACH COST BUILD-UP FOR REFERENCE MISSION C

- ORBIT

  1000 KM (540 NM) CIRCULAR
  57° INCLINATION

- PAYLOAD

  WEIGHT - 1000 KG (2205 LB)
  LENGTH - 3M (9.84 FT)
  DIAMETER - 4.5M (14.76 FT)

| PROPULSION APPROACH | STAGE WEIGHT KG (LB) | ASE WEIGHT KG (LB) | LAUNCH WEIGHT KG (LB) | BAY INSTL. H OR V | BAY LENGTH INCLUDING PAYLOAD M (FT) | UNIT COST $M | SHUTTLE CHARGE $M | USER COST $M |
|---|---|---|---|---|---|---|---|---|
| MODULAR 4 TANK BIPROPELLANT | 516.8 (1139.3) | 583.3 (1286.0) | 2100.1 (4630.3) | H | 3.7 (12.15) | 1.07 | 5.91 L (1) | 6.98 |

(1) L = LENGTH CRITICAL

TABLE III—XXVII PROPULSION APPROACH COMBINATIONS

| REF. MISSION / COST ORDER | A 10,000 KG 500 KM 28.5° INCL | | B 3,000 KG 1,000 KM 97° INCL | | C 1,000 KG 1,000 KM 57° INCL | | D 200 KG 577 KM 98.5° INCL | | E 170 KG 1,111 KM 2.8° INCL | | F 200 KG 1,000 KM 97.5° INCL | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | APPROACH | COST $M | APPROACH | COST $M | APPROACH | COST $M | APPROACH | COST $M | APPROACH | COST $M | APPROACH | COST $M |
| 1 | INTEGL OMS | 21.48 | FLAT PACK 6-LONG | 16.61 | 4 T-MONOPROP. | 6.85 | STAR 17A/ STAR 17 (V) | 3.24 | LIQUID QUENCH (V) | 3.81 | S.STAR 48/ S.STAR 37F | 9.51 |
| 2 | 6 T-BIPROP. | 23.53 | 8 TANK BIPROP (MODULAR) | 16.88 | FLAT PACK 4 SHORT | 6.88 | 4 STAR 17 (V) | 3.33 | PINTLE-LARGE (V) | 3.82 | STAR 48/ STAR 37F | 9.97 |
| 3 | 8 T-MONOPROP. | 23.54 | 8 T-MONO-PROP (MODULAR) | 17.13 | 4 T-BIPROP. | 6.89 | STAR 26/ STAR 26 (V) | 3.75 (W) | S.STAR 37F/ S.STAR 37S (V) | 4.16 (W) | MM III/8T-BIPROP. (MODULAR) | 10.34 |
| 4 | 8 T-BIPROP. | 23.55 | LIQUID QUENCH | 17.89 | 4 T BIPROP. | 6.91 | PINTLE-SMALL (V) | 3.78 (W) | 8 T-BIPROP. (MODULAR) | 5.23 | | |
| 5 | FLAT PACK 6 SHORT | 23.69 | PINTLE-LARGE | 18.07 | 4 T-BIPROP. (MODULAR) | 6.98 | 3 T-MONO-PROP. | 4.71 | S.STAR 48/ 4 T-BIPROP.(V) | 5.68 | | |
| 6 | 4 T-BIPROP. (MODULAR) | 23.78 | 22 STAR 17 | 18.09 | 2-TANK MONO-PROP. (MODULAR) | 7.07 | 4 T-BIPROP. (V) | 4.86 | STAR 37E/ 4 T-BIPROP.(V) | 5.86 | | |
| 7 | 4 T-MONOPROP. (MODULAR) | 24.00 | STAR37E/ 6T-BIPROP | 19.17 | 4 STAR 17 | 7.11 | FLAT PACK 4 SHORT | 4.98 | S.STAR 48/ 2 T-MONO-PROP (V) | 5.93 | | |
| 8 | 7 STAR 17 | 24.19 | S.STAR 48/ 4 T-BIPROP. | 19.23 | PINTLE-SMALL | 8.06 | 4 T-BIPROP. | 5.08 | 22 STAR 17 (V) | 6.59 | | |
| 9 | PINTLE-SMALL – | 24.90 | SST48/ 4T-MONOPROP | 19.33 | LIQUID QUENCH | 8.20 | 4 T-BIPROP. (MODULAR) | 6.20 | STAR 48/ STAR 26 | 8.87 | | |
| 10 | LIQUID QUENCH | 24.95 | S.STAR 37F/ S.STAR 37S | 19.60 | PINTLE-LARGE | 8.45 | 2 T-MONO-PROP (MODULAR) | 5.15 | STAR 48/ 4 T-BIPROP. (MODULAR) | 8.88 | | |
| 11 | PINTLE-LARGE | 25.16 | STAR 48/ STAR 26 | 20.58 | STAR 17A/ STAR 17 | 8.57 | LIQUID QUENCH (V) | 5.66(W) | S.STAR 48/ S.STAR 37S | 8.89 | | |
| 12 | STAR 26/ STAR 26 | 25.78 | S.STAR 48/ STAR 37S | 20.38 | STAR 26/ STAR 26 | 8.90 | PINTLE-LARGE (V) | 5.74(W) | S.STAR 48/ S.STAR 37F | 9.51 | | |
| 13 | STAR 48/ 2T-MONOPROP. | 26.45 | S.STAR 48/ S.STAR 37F | 20.95 | S.STAR 48/ S.STAR 37 | 10.82 | S.STAR 48/ S.STAR 37 | 8.89 | STAR 48/ STAR 37F | 9.97 | | |
| 14 | STAR 48/ STAR 26 | 27.43 | STAR 48/ STAR 37 | 21.43 | STAR 48/ STAR 26 | 10.84 | STAR 48/ STAR 26 | 8.92 | | | | |
| 15 | S.STAR 48/ S.STAR 37S | 27.47 | | | | | | | | | | |
| NUMBER OF PAYLOADS | 17 | | 38 | | 32 | | 22 | | 6 | | 10 | |

V – INDICATESCONFIGURATION IS INSTALLED VERTICALLY, ALL OTHERS ARE INSTALLED HORIZONTALLY

W – INDICATES SHUTTLE CHARGE IS DETERMINED BY WEIGHT, ALL OTHERS ARE DETERMINED BY LENGTH

STAR 48 IS SSUS-D, S. STAR 48 OR SST 48 IS SHORT NOZZLE SSUS-D
MM III IS SSUS-A

adaptations of existing/planned propulsion approaches evaluated. The costs include stage unit cost and Shuttle user charge for the stage and payload. Vertical installations are noted by a "V" where they are possible and lower in cost than horizontal installations. Where the weight load factor for the stage, payload and ASE determined the Shuttle user charge, it is noted by a "W".

Using reference mission C as a typical example, Figure 3.12 is a bar chart plot of the costs shown in Table 3-XXVII. Shown are the propulsion approach description and a breakdown of the total user charge by unit stage cost, Shuttle user charge for the stage and for the payload. For reference mission C payloads used in this example, the length of three meters (9.84 ft.) combined with the stage length did not permit vertical installation. Length load factor for the stage and payload was greater than the weight load factor for the stage, payload, and ASE for all propulsion approaches; thus the Shuttle user charge was based on the length of cargo bay required for this reference mission.

### 3.4.2 Screening by Propulsion Approach Combination

Cost ranking by reference mission was used as a shopping list for candidate combinations of propulsion approaches. The modular bipropellant approach shown in heavy bordered boxes in Table 3-XXVIII is a typical logical approach to launch all of the reference missions. Consideration of the relative cost weighting of each reference mission was made using the reference mission payload quantities also shown in the table. Another logical approach would be to use the integral OMS for reference mission A and the modular bipropellant for all others. Using this procedure, a series of logical combinations of approaches were selected that have the potential of being the lowest cost to launch the 125 payloads represented by the reference missions.

The total user cost buildup of the integral OMS, modular bipropellant and the MM III/modular bipropellant combination is shown in Table 3-XXIX. This example is typical of the costing procedure applied to the series of logical combinations selected from the propulsion approach cost ranking by reference mission. A description of this example follows:

- Integral OMS launches reference mission A payloads in this combination. While one OMS kit would be required to deliver a total of 29483 kg (65000 lbs.) to orbit, an analysis shows that anticipated payload

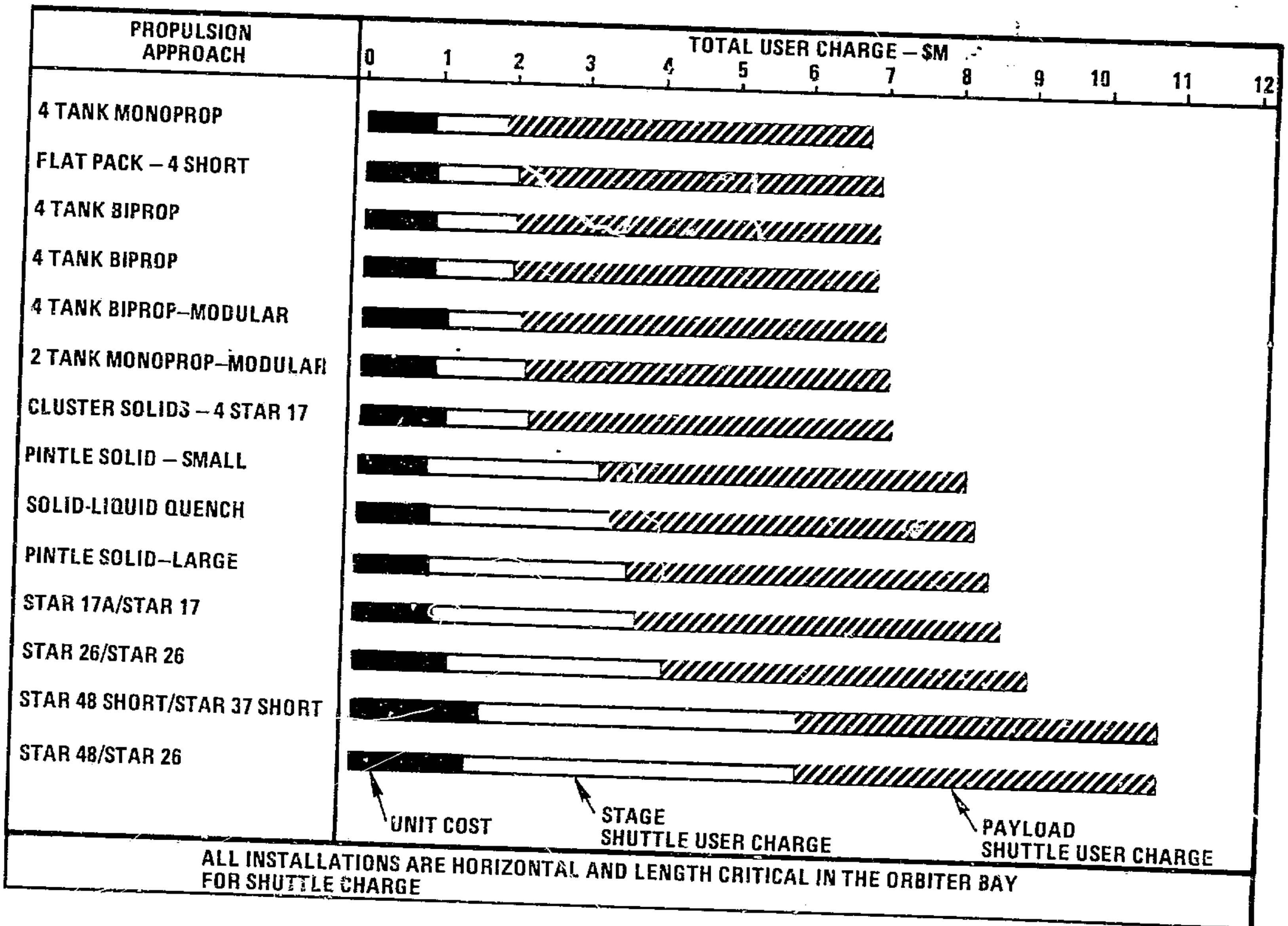



FIGURE 3.12 PROPULSION APPROACH COST RANKING FOR REFERENCE MISSION C

TABLE 3-XXVIII PROPULSION APPROACH COMBINATIONS

| REF. MISSION / COST ORDER | A 10,000 KG 500 KM 28.5° INCL | | B 3,000 KG 1,000 KM 97° INCL | | C 1,000 KG 1,000 KM 57° INCL | | D 200 KG 577 KM 96.5° INCL | | E 170 KG 1,111 KM 2.9° INCL | | F 200 KG 1,000 KM 97.5° INCL | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | APPROACH | COST SM | APPROACH | COST SM | APPROACH | COST SM | APPROACH | COST SM | APPROACH | COST SM | APPROACH | COST SM |
| 1 | INTEGL OMS | 21.48 | FLAT PACK 6-LONG | 16.61 | 4 T-MONOPROP. | 6.65 | STAR 17A/ STAR 17 (V) | 3.24 | LIQUID QUENCH (V) | 3.81 | S.STAR 48/ S.STAR 37F | 9.51 |
| 2 | 6 T-BIPROP. | 23.53 | 8 TANK BIPROP (MODULAR) | 16.88 | FLAT PACK 4 SHORT | 6.88 | 4 STAR 17 (V) | 3.33 | PINTLE-LARGE (V) | 3.82 | STAR 48/ STAR 37F | 9.97 |
| 3 | 8 T-MONOPROP. | 23.54 | 8 T-MONO-PROP (MODULAR) | 17.13 | 4 T-BIPROP. | 6.89 | STAR 26/ STAR 26 (V) | 3.75 (W) | S.STAR 37F/ S.STAR 37S (V) | 4.10 (W) | MM III/8T-BIPROP. (MODULAR) | 10.34 |
| 4 | 8 T-BIPROP. | 23.55 | LIQUID QUENCH | 17.89 | 4 T-BIPROP. | 6.91 | PINTLE-SMALL (V) | 3.78 (W) | 8 T-BIPROP. (MODULAR) | 5.23 | | |
| 5 | FLAT PACK 6 SHORT | 23.69 | PINTLE-LARGE | 18.07 | 4 T-BIPROP. (MODULAR) | 6.98 | 3 T-MONO-PROP. | 4.71 | S.STAR 48/ 4 T-BIPROP. (V) | 5.68 | | |
| 6 | 4 T-BIPROP. (MODULAR) | 23.78 | 22 STAR 17 | 18.09 | 2 TANK MONO-PROP. (MODULAR) | 7.07 | 4 T-BIPROP. (V) | 4.86 | STAR 37E/ 4 T-BIPROP. (V) | 5.86 | | |
| 7 | 4 T-MONOPROP. (MODULAR) | 24.00 | STAR37E/ 6T-BIPROP | 19.17 | 4 STAR 17 | 7.11 | FLAT PACK 4 SHORT | 4.98 | S.STAR 48/ 2 T-MONO-PROP (V) | 5.93 | | |
| 8 | 7 STAR 17 | 24.19 | S.STAR 48/ 4 T-BIPROP. | 19.23 | PINTLE-SMALL | 8.06 | 4 T-BIPROP. | 5.08 | 22 STAR 17 (V) | 6.59 | | |
| 9 | PINTLE-SMALL | 24.90 | SST48/ 4T-MONOPROP | 19.33 | LIQUID QUENCH | 8.20 | 4 T-BIPROP. (MODULAR) | 5.20 | STAR 48/ STAR 26 | 8.87 | | |
| 10 | LIQUID QUENCH | 24.95 | S.STAR 37F/ S.STAR 37S | 19.60 | PINTLE-LARGE | 8.45 | 2 T-MONO-PROP (MODULAR) | 5.15 | STAR 48/ 4 T-BIPROP. (MODULAR) | 8.88 | | |
| 11 | PINTLE-LARGE | 25.16 | STAR 48/ STAR 26 | 20.58 | STAR 17A/ STAR 17 | 8.57 | LIQUID QUENCH (V) | 5.66(W) | S.STAR 48/ S.STAR 37S | 8.89 | | |
| 12 | STAR 26/ STAR 26 | 25.78 | S.STAR 48/ STAR 37S | 20.38 | STAR 26/ STAR 26 | 8.90 | PINTLE-LARGE (V) | 5.74(W) | S.STAR 48/ S.STAR 37F | 3.51 | | |
| 13 | STAR 48/ 2T-MONOPROP. | 26.45 | S.STAR 48/ S.STAR 37F | 20.95 | S.STAR 48/ S.STAR 37 | 10.82 | S.STAR 48/ S.STAR 37 | 6.89 | STAR 48/ STAR 37F | 9.97 | | |
| 14 | STAR 48/ STAR 26 | 27.43 | STAR 48/ STAR 37 | 21.43 | STAR 48/ STAR 26 | 10.84 | STAR 48/ STAR 26 | 8.92 | | | | |
| 15 | S.STAR 48/ S.STAR 37S | 27.47 | | | | | | | | | | |
| NUMBER OF PAYLOADS | 17 | | 38 | | 32 | | 22 | | 6 | | 10 | |

V – INDICATES CONFIGURATION IS INSTALLED VERTICALLY, ALL OTHERS ARE INSTALLED HORIZONTALLY

W – INDICATES SHUTTLE CHARGE IS DETERMINED BY WEIGHT, ALL OTHERS ARE DETERMINED BY LENGTH

## TABLE 3-XXIX TYPICAL COST BUILD-UP FOR COMBINATIONS OF PROPULSION APPROACHES

| PROPULSION APPROACH COMBINATION | | REFERENCE MISSIONS/NUMBER OF PAYLOADS | | | | | | | | | | | | TOTAL COST $M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | | B | | C | | D | | E | | F | | |
| | | 17 | | 38 | | 32 | | 22 | | 6 | | 10 | | |
| | | STAGE COST | SHUTTLE CHARGE | STAGE COST | SHUTTLE CHARGE | STAGE COST | SHUTTLE CHARGE | STAGE COST | SHUTTLE CHARGE | STAGE COST | SHUTTLE CHARGE | STAGE COST | SHUTTLE CHARGE | |
| INTEGRAL OMS | $M | 0 | 0 | | | | | | | | | | | |
| 8 TANK MODULAR BIPROPELLANT | $M | | | 1.41 | 1.3 | | | | | 1.41 | 1.12 | | | |
| 4 TANK MODULAR BIPROPELLANT | $M | | | | | 1.21 | 1.12 | 1.21 | 1.12 | | | | | |
| MM III/8 TANK MODULAR BIPROPELLANT | $M | | | | | | | | | | | 2.41 | 5.24 | |
| PAYLOAD SHUTTLE CHARGE | $M | | 21.48 | | 14.33 | | 4.8 | | 2.88 | | 2.86 | | 3.04 | |
| TOTAL STAGE COST | $M | 0 | | 53.6 | | 38.7 | | 26.6 | | 8.5 | | 24.1 | | 151.5 |
| TOTAL SHUTTLE CHARGE | $M | | 365.2 | | 593.9 | | 199.4 | | 88.0 | | 23.9 | | 82.8 | 1,343.2 |
| COMBINATION DEV COST | | | | | | | | | | | | | | 19.8 |
| ASE DEVELOPMENT COST | | | | | | | | | | | | | | 10.5 |
| PROGRAM MAINTENANCE COST | | | | | | | | | | | | | | 62.1 |
| TOTAL USER COST | | | | | | | | | | | | | | 1,587.1 |

density and lengths make the integral OMS a practical candidate. For example, the Reference Mission A payload, representative of payloads in this class, weighs 10000 kg (22046 lbs.) and is 13.5m (44.3 ft.) long. This corresponds to a length load factor of .74 and a user charge factor of approximately 1.0. Integral OMS can deliver the Reference Mission A payload to the 500 km (270 nm) circular orbit and de-orbit to earth. For shorter payloads of the same density, multiple payloads could be delivered by integral OMS to both 296 km (160 nm) and 500 km (270 nm) orbits. There is no stage cost or Shuttle user charge for a stage in this case, only the payload Shuttle charge is accrued.

- An eight-tank version of the modular bipropellant approach is used for Reference Missions B and E and a four-tank version for Reference Missions C and D. For Reference Mission F the eight-tank version is used as a second stage on the Spinning Minuteman III third stage. Unit costs and Shuttle user charge for horizontal installations, required for this combination, is shown for each reference mission payload. The number of payloads represented by each reference mission is multiplied by the unit stage cost to give the total stage cost and by the stage Shuttle charge plus the payload Shuttle charge to give the total Shuttle charge. These are summed to get total cost to launch all payloads.

- The development cost for the combination is the cost to develop the modular four- and eight-tank versions of the bipropellant and to integrate the eight-tank version with the Spinning Minuteman III third stage. The ASE development cost includes the cost for development and design integration of the airborne support equipment for the four- and eight-tank versions and the cost of three sets of this ASE. Also included is the cost to integrate with the Spinning Minuteman III third stage ASE.

- Program maintenance costs consist of annual program sustaining costs and operations costs made up of system engineering and integration and annual site operation costs. In this example the program sustaining costs are 21.24 \$M, the system engineering and integration costs 27.86 \$M and the annual site operation cost 13.01 \$M for the total of 62.1 \$M.

Nineteen combinations of propulsion approaches were examined and costs, as shown in Table 3-XXIX, were built-up for 15 of these. Costs for the top ten of these are shown in Table 3-XXX. Of the four combinations

## TABLE 3-XXX COST RANKING BY PROPULSION APPROACH COMBINATIONS —TOP 10 OF 19 COMBINATIONS —

| COST ORDER | MISSION / COMBINATION NO. | A | B | C | D | E | F | TOTAL COST M $ |
|---|---|---|---|---|---|---|---|---|
| | | LAUNCH COMBINATION DESCRIPTION | | | | | | |
| 1 | 2 | INTEGL OMS | MODULAR 8T-BIPROP | MODULAR 4T-BIPROP | MODULAR 4T-BIPROP | MODULAR 8T-BIPROP | MM III/ MODULAR 8T-BIPROP | 1587 |
| 2 | 4 | INTEGL OMS | FLATPACK 6-LONG | FLATPACK 4-SHORT | FLATPACK 4-SHORT | S-STAR 48/ S-STAR 37F | S-STAR 48/ S-STAR 37F | 1605 |
| 3 | 9 | INTEGL OMS | MODULAR 8T-BIPROP | MODULAR 4T-BIPROP | MODULAR 4T-BIPROP | STAR 48/ MODULAR 4T-BIPROP | MM III/ MODULAR 8T-BIPROP | 1618 |
| 4 | 12 | INTEGL OMS | 22 STAR 17 | 4 STAR 17 | 4 STAR 17 | 22 STAR 17 | S-STAR 48/ S-STAR 37F | 1627 |
| 5 | 7 | INTEGL OMS | MODULAR 8T-MONOPROP | MODULAR 2T-MONOPROP | MODULAR 2T-MONOPROP | S-STAR 48/ S-STAR 37F | S-STAR 48 S-STAR 37F | 1630 |
| 6 | 15 | INTEGL OMS | PINTLE-L | PINTLE-S | PINTLE-S | PINTLE-L | S-STAR 48/ S-STAR 37F | 1638 |
| 7 | 6 | MODULAR 4T-BIPROP | MODULAR 8T-BIPROP | MODULAR 4T-BIPROP | MODULAR 4T-BIPROP | MODULAR 8T-BIPROP | MM III/ MODULAR 8T-BIPROP | 1641 |
| 8 | 10 | INTEGL OMS | LIQUID QUENCH | LIQUID QUENCH | LIQUID QUENCH | LIQUID QUENCH | S-STAR 48/ S-STAR 37F | 1674 |
| 9 | 11 | INTEGL OMS | PINTLE-L | PINTLE-L | PINTLE-L | PINTLE-L | S-STAR 48/ S-STAR 37F | 1685 |
| 10 | 14 | INTEGL OMS | S-STAR 48/ S-STAR 37F | STAR 17A/ STAR 17 | STAR 17A/ STAR 17 | S-STAR 48/ S-STAR 37F | S-STAR 48/ S-STAR 37F | 1801 |

that were not costed it was determined, by inspection, that two solid/solid combinations were higher in cost than the solid/solid combination evaluated; one was a bipropellant combination higher in cost than the evaluated bipropellant combination; and one was a monopropellant higher in cost than the evaluated monopropellant combinations.

Five combinations were costed but eliminated from consideration. One of these was the lowest unit cost for each reference mission. It consisted of six different approaches; Integral OMS - Mission A; Flat Pack - Mission B; Monopropellant - Mission C; Star 17A/Star 17 - Mission D; Liquid Quench - Mission E and Short Spinning Star 48/Short Star 37F - Mission F. The resulting user cost for this combination was low as would be expected; however, the program maintenance and development costs were very high. This combination was eliminated from further consideration. The second combination that was eliminated was identical to combination number 2 except for Missions E and F which were launched by a Short Spinning Star 48/Short Star 37F. This combination was significantly higher in cost than combination 2. The third combination eliminated was identical to combination number 12 except that Mission A was launched by a 6-short-motor Flat Pack. This combination was significantly higher in cost than combination 12. The fourth combination eliminated consisted of Integral OMS for Mission A, Star 37E/Six-Tank Bipropellant for Missions B and E, a Four-Tank Bipropellant for Missions C and D, and a Short Spinning Star 48/Short Star 37F for Mission F. The costs for this solid/liquid combination were much higher than combination 9. The fifth combination eliminated was identical to combination 7 except that Mission A was launched by a Four-Tank Monopropellant. The costs for this combination were much higher than combination number 9.

Liquid propulsion approaches are represented by combinations 2, 9, 7 and 6; solid/solid propulsion approaches by combination 14; controlled solids by combinations 15, 10 and 11; and solid/solid cluster approaches by combinations 4 and 12. Combination 6 shows the cost impact of replacing the Integral OMS with a liquid stage for Reference Mission A payloads. Combinations 2, 6 and 9 show the adaptation of existing/planned Shuttle upper stages.

A graphic comparison of the costs of the top ten propulsion approach combinations is shown in Figure 3.13. Approximately 25% of the

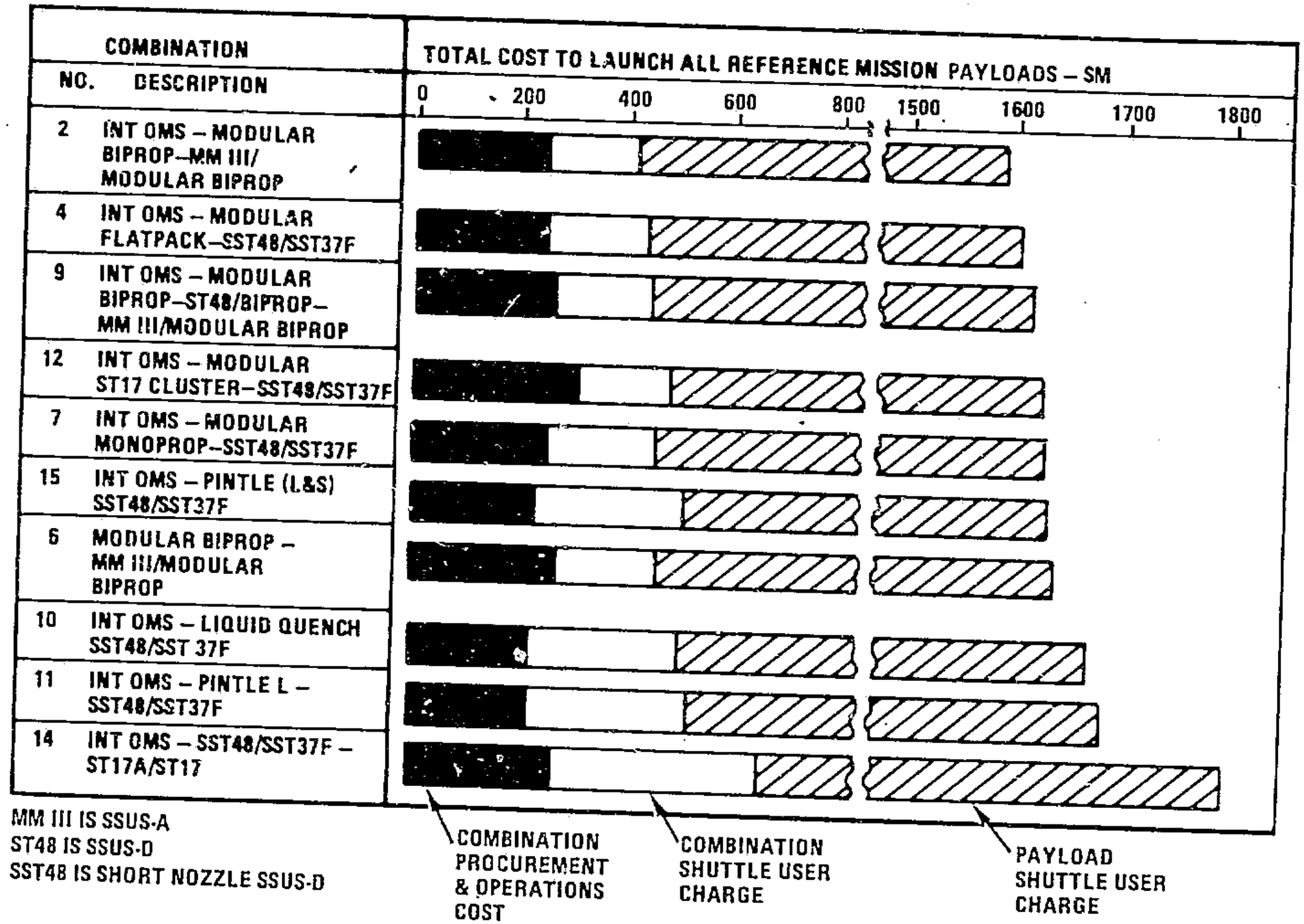



FIGURE 3.13 COST COMPARISON OF PROPULSION APPROACH COMBINATIONS

total cost is a function of the propulsion approach and 75% is attributable to the Shuttle charge for the payload; therefore the propulsion approach costs amount to about 420 $M in the case of combination number 2. Costs within 10% of combination 2 are considered to be essentially equal and a benefits analysis was performed to adjust the ranking prior to final selection of propulsion approaches. Based on this procedure, combinations 2, 4, 9, 12 and 7 qualified for deeper penetration. Combinations 2 and 9 were grouped together as a modular bipropellant, therefore, the propulsion approaches selected for additional benefits analysis were the modular bipropellant combinations 2 and 9, the flat pack combination 4, the Star 17 cluster combination 12, and the modular monopropellant combination 7.

### 3.4.3 Benefits Analysis

Mission capture, accuracy and risk for the four lower cost propulsion approaches were evaluated, as shown in Table 3-XXXI. Mission capture rating, rated on a one-to-ten basis with ten high was derived by calculating the percent of reference missions captures and then dividing by 10. Mission capture measured the program advantage of a single approach. The modular bipropellant, which can deliver five of the six reference mission payloads has a rating of 8. The modular monopropellant captures four reference mission payloads and has a rating of 7. The Flat Pack has a rating of 7. The Star 17 cluster captures all but Mission F and has a rating of 8.

Accuracy is rated on a one-to-ten basis with ten high. Wasting excess energy by yaw steering fixed-impulse propulsion approaches produces errors in destination orbits. The accuracy rating equation is designed to produce a rating of 1 when the ratio of wasted energy to energy required is 3.0. Also, each accuracy degrading characteristic penalizes the accuracy rating one point. Liquid approaches do not waste excess velocity, thus have no accuracy degrading characteristics. The flat pack sized for mission C wastes about 40% of its energy for mission D. Also, aligning many solid rocket motors to thrust through the system center of gravity along with pointing inaccuracy from thrust buildup characteristics of multi-motors results in an accuracy rating of 7 for the flat pack. A similar rating was derived for the cluster of Star 17s, but its energy waste was greater and produced a rating of 6.

## TABLE 3–XXXI BENEFIT ANALYSIS

| PROPULSION APPROACH | MISSION CAPTURE RATING | ACCURACY | | RISK | | TOTAL BENEFIT RATING | CONCLUSIONS |
|---|---|---|---|---|---|---|---|
| | | LOGIC | RATING | LOGIC | RATING | | |
| MODULAR BIPROPELLANT | 8 | • NO ΔV WASTED<br>• NO ACCURACY DEGRADING CHARACTERISTICS | 10 | • HARDWARE DEVELOPMENT REQUIRED FOR:<br>– TANKAGE<br>– GUIDANCE INTEGRATION | 8 | 26 | ACCEPTABLE FOR ADDITIONAL STUDY |
| MODULAR MONOPROPELLANT | 7 | • SAME AS BIPROPELLANT | 10 | • SAME AS BIPROPELLANT | 8 | 25 | ACCEPTABLE FOR ADDITIONAL STUDY |
| FLAT PACK | 7 | • $\frac{\Delta V \text{ WASTED}}{\Delta V \text{ REQ'D}} = .4$<br>• MULTI MOTOR THRUST ALIGNMENT<br>• UNSYMMETRICAL THRUST BUILDUP | 7 | • HARDWARE DEVELOPMENT REQUIRED FOR:<br>– GUIDANCE INTEG.<br>– UNSYMMETRICAL THRUST BUILDUP SENSOR<br>– UNSYMMETRICAL THRUST CORRECTION | 7 | 21 | ACCEPTABILITY FOR ADDITIONAL STUDY MARGINAL DUE TO POTENTIAL ACCURACY AND RISK PROBLEMS |
| STAR 17 CLUSTER | 8 | • $\frac{\Delta V \text{ WASTED}}{\Delta V \text{ REQ'D}} = .52$<br>• MULTI MOTOR THRUST ALIGNMENT<br>• UNSYMMETRICAL THRUST BUILDUP | 6 | • SAME AS FLAT PACK<br>• RELIABILITY OF STAR 17 CLUSTER < .98 | 1<br>(1) | 15 | NOT ACCEPTABLE DUE TO RISK |

MISSION CAPTURE RATING = PERCENT OF REFERENCE MISSIONS CAPTURED ÷ 10

ACCURACY RATING $= 10 - 3\,\frac{\Delta V \text{ WASTED}}{\Delta V \text{ REQUIRED}}$ – NUMBER OF ACCURACY DEGRADING CHARACTERISTICS

RISK RATING = 10 – (NUMBER OF TECHNOLOGY DEVELOPMENTS REQUIRED + NUMBER OF HARDWARE DEVELOPMENTS REQUIRED)

NOTE: (1) REDUCED FROM 7 TO 1 BECAUSE OF RELIABILITY

Risk rating is on a one-to-ten basis with ten indicating low risk. The rating is degraded from ten for each technology and hardware development required. None of these approaches require technology development. Required sizes of metal bladder conospherical tanks require hardware development. Integration of a computer with a roll stabilized platform requires interfacing hardware and software development. The resultant risk rating is 8 for the two liquid approaches. The flat pack has the same guidance integration hardware development requirement, and must have hardware developed to sense and correct pointing error due to thrust misalignment and unsymmetrical thrust buildup - thus a rating of 7. In addition to these risk rating degrading factors, the 22 Star 17 cluster has multi-motor reliability of less than .98 based on an individual motor reliability of .999. The potential loss of 2 out of 100 launches due to propulsion malfunction was not considered acceptable state-of-the-art design. This was not correctable by reasonable technology or hardware development and the risk rating was reduced to an unacceptable level of 1.

Based on the total benefit rating only the two liquid approaches were considered acceptable for additional study.

### 3.4.4 Propulsion Approach Selection

New and adaptation of existing/planned propulsion approaches that were selected for detailed analysis and cost/benefit evaluation against the specific payloads of the new payload model are shown in Table 3-XXXII.

3.4.4.1 Selection of New and Adaptation Approaches - The modular bipropellant and the modular monopropellant approaches ranked high in benefits and low in user cost and were first and second choices respectively for new propulsion approaches. An alternate to the integral OMS for Mission A was provided by the four-tank version of the bipropellant for no additional development cost. This was a reasonable alternate as shown by Table 3-XXVII.

An alternate to the higher energy requirements of Mission E was provided by the modular four-tank bipropellant as the upper stage for the Spinning Star 48. The propulsion approach selected for Mission F was the eight-tank bipropellant as the upper stage for the Spinning Minuteman III third stage.

3.4.4.2 Modular Bipropellant Configuration - The modular bipropellant propulsion approach, Figure 3.14, was configured to minimize Shuttle installation length through use of multiple identical conospherical propellant

TABLE 3-XXXII PROPULSION APPROACH SELECTION FOR DETAILED ANALYSIS

| PROP. APPROACH \ REF. MISSION | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| ADAPTATIONS OF EXISTING APPROACHES | | | | | STAR 48/ MODULAR 4-TANK BIPROP | MM III/ MODULAR 8-TANK BIPROP |
| NEW APPROACHES | MODULAR 4-TANK BIPROP | MODULAR 8-TANK BIPROP | MODULAR 4-TANK BIPROP | MODULAR 4-TANK BIPROP | MODULAR 8-TANK BIPROP | |
| | | MODULAR 8-TANK MONOPROP | MODULAR 2-TANK MONOPROP | MODULAR 2-TANK MONOPROP | | |
| TOTAL FOR EACH MISSION | 1 | 2 | 2 | 2 | 2 | 1 |

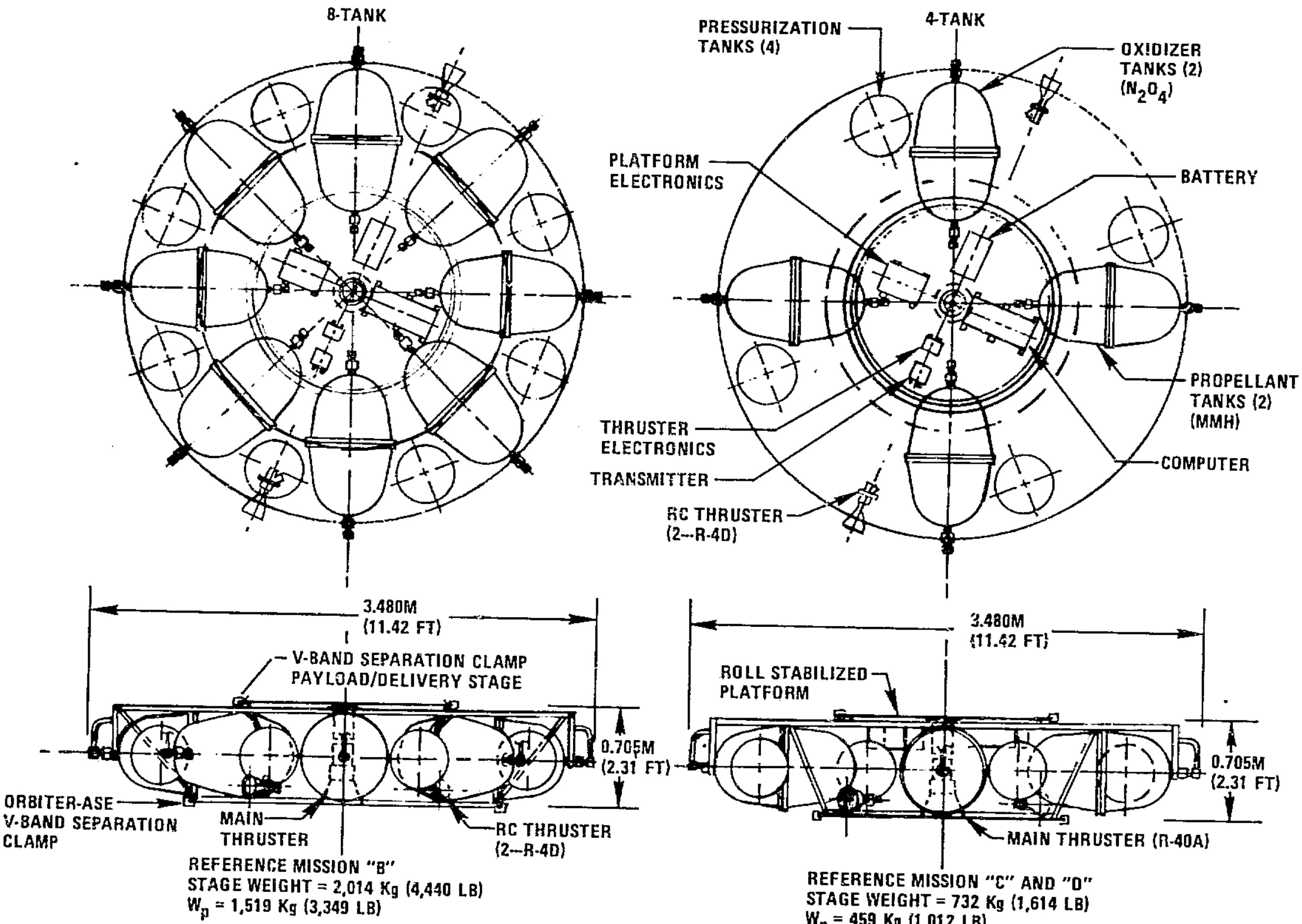



FIGURE 3.14 MODULAR BIPROPELLANT

tanks arranged with centerlines normal to the stage centerline. Propellant transfer under varying loads and maneuvers was accomplished by use of tankage incorporating metal diaphragms for single phase flow and center of gravity control. Tankage was prepackaged and required no servicing at the launch site. A regulated helium system was used for propellant pressurization. A single R-40A 3870 N (870 $lb_f$) thruster (Space Shuttle reaction control thruster) located on the stage centerline provided both perigee and apogee velocity increments. In applications for Reference Missions B through F, the stage employed a spin stabilized guidance and control system consisting of a computer, roll stabilized platform and control electronics. Maneuver and nutation control was provided by one and two R-4D thrusters (Missions B and C, D, E, F, respectively).

Propellant tankage and other components were sized for an eight-tank fully loaded configuration for Mission B. A four-tank, off-loaded derivative satisfied Missions C and D requirements. Stage length was consistent with propellant tankage diameter as well as the combined lengths of the roll stabilized platform and the main thruster (both were on the stage centerline). Diameter of the eight-tank configuration was governed by the number of propellant tanks, tank length, and plumbing requirements. For the four-tank system, due to the fewer propellant tanks, the diameter was less than the eight-tank system.

3.4.4.3 Modular Monopropellant -- Similar to the bipropellant system, the modular monopropellant propulsion approach, Figure 3.15, was configured to minimize Shuttle installation length through use of multiple, identical conospherical propellant tanks arranged with centerlines normal to the stage centerline. Propellant transfer under varying loads and maneuvers was accomplished by use of tankage incorporating metal diaphragms which also provide single phase flow and center of gravity control. Since tankage was prepackaged, no servicing was required at the launch site. Propellant pressurization was by a regulated helium system. Four MR-104, 623 N (140 $lb_f$) thrusters (Mariner Jupiter/Saturn 77 RCS) located on the outer stage circumference, 90° apart and parallel to the stage centerline provided both perigee and apogee velocity increments as well as maneuver and nutation control. For Missions B through E, the stage employed a roll stabilized guidance and

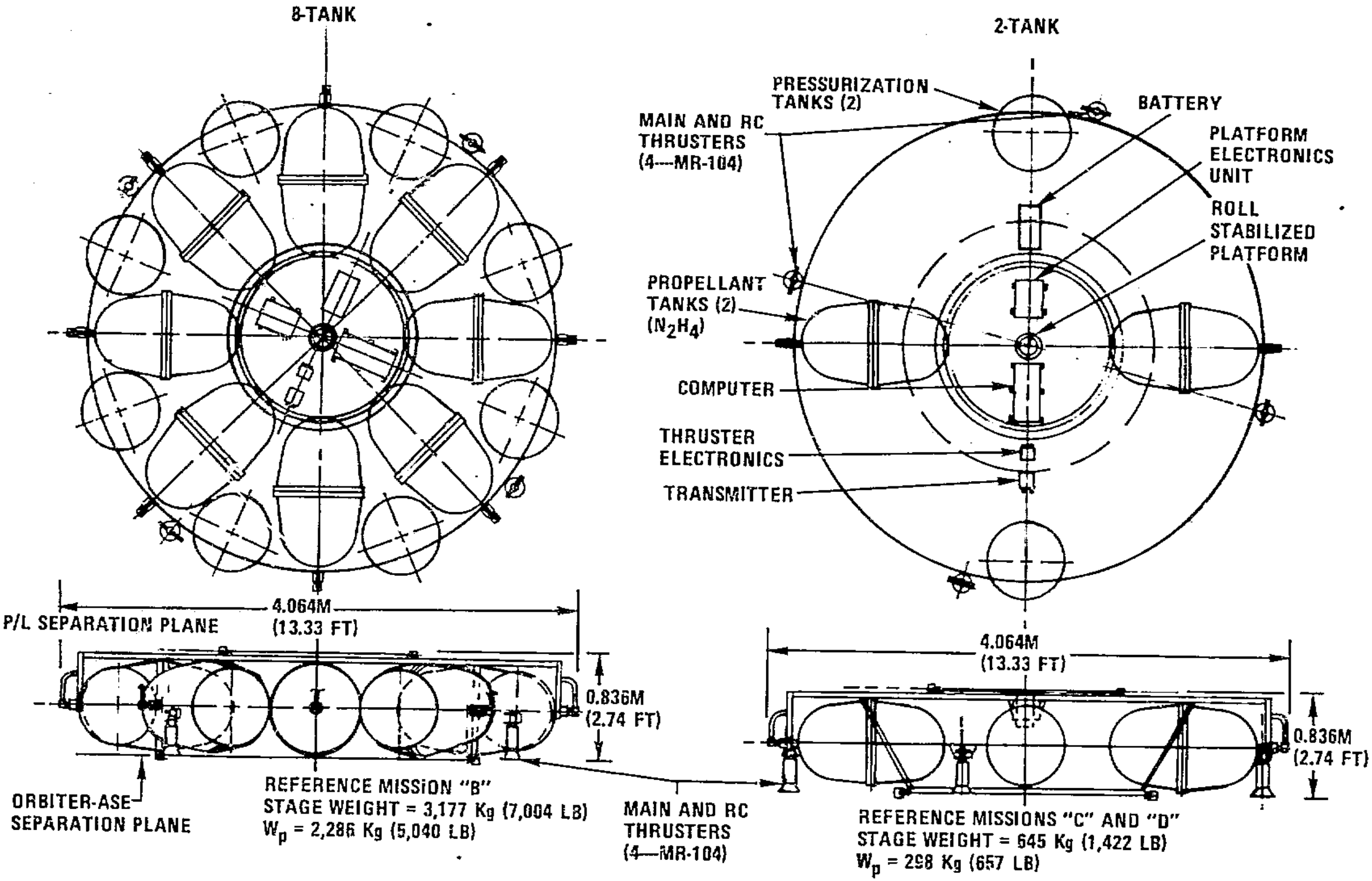



FIGURE 3.15 MODULAR MONOPROPELLANT

control system consisting of a computer, roll stabilized platform and control electronics. Propellant tankage and other components were sized for an eight-tank, fully loaded configuration for Mission B. A two-tank, off-loaded derivative satisfied missions C and D requirements. Stage length was established primarily by propellant tank diameter. Diameter of the eight tank configuration is governed by the number of propellant tanks, tank length and plumbing requirements. For the two-tank version, the diameter is less than the eight-tank system. Since propellant density and performance were lower, the monopropellant package size was larger than the bipropellant system.

3.4.4.4 Adaptation of Existing/Planned Approaches - In the left side of Figure 3.16, the spin-stabilized modular bipropellant propulsion approach is combined with the Spinning Minuteman III (SSUS-A) third stage for Reference Mission F. The bipropellant stage is the same as the 8-tank modular bipropellant and provides apogee velocity increment.

The spin-stabilized modular bipropellant approach was combined with the Spinning Star 48 (SSUS-D) stage for Reference Mission F. The bipropellant stage is the same as the 4-tank modular bipropellant, and provides the apogee velocity increment.

3.4.4.5 Existing/Planned Launch Approaches - The existing/planned launch approaches for additional evaluation in the LES study are shown in Figure 3.17. Both integral OMS and OMS kits were considered in Task 6 (Volume IV) for delivery of payloads that have been represented by Reference Mission A as well as for other applicable payloads. The Teleoperator Retrieval System in both two-tank and four-tank versions was considered in Task 6 (Volume IV) for delivery of all payloads for which it has adequate performance. The Multimission Modular Spacecraft (MMS) with a PMII propulsion module was considered for those payloads using the MMS. The Scout expendable launch vehicle was also evaluated in Task 6 (Volume IV) for those payloads it can deliver to their destination orbits.

3.4.4.6 Total Propulsion Approaches Carried Forward - A summary of the total propulsion approaches carried forward in the study is shown in Table 3-XXXIII. Conceptual designs, STS interface analysis and flight and ground operations analysis are presented on the new approaches and adaptations in Tasks 3, 4 and 5 (Volume III). Cost/benefit analysis of new, adaptation and existing/planned approaches is presented in Task 6 (Volume IV).

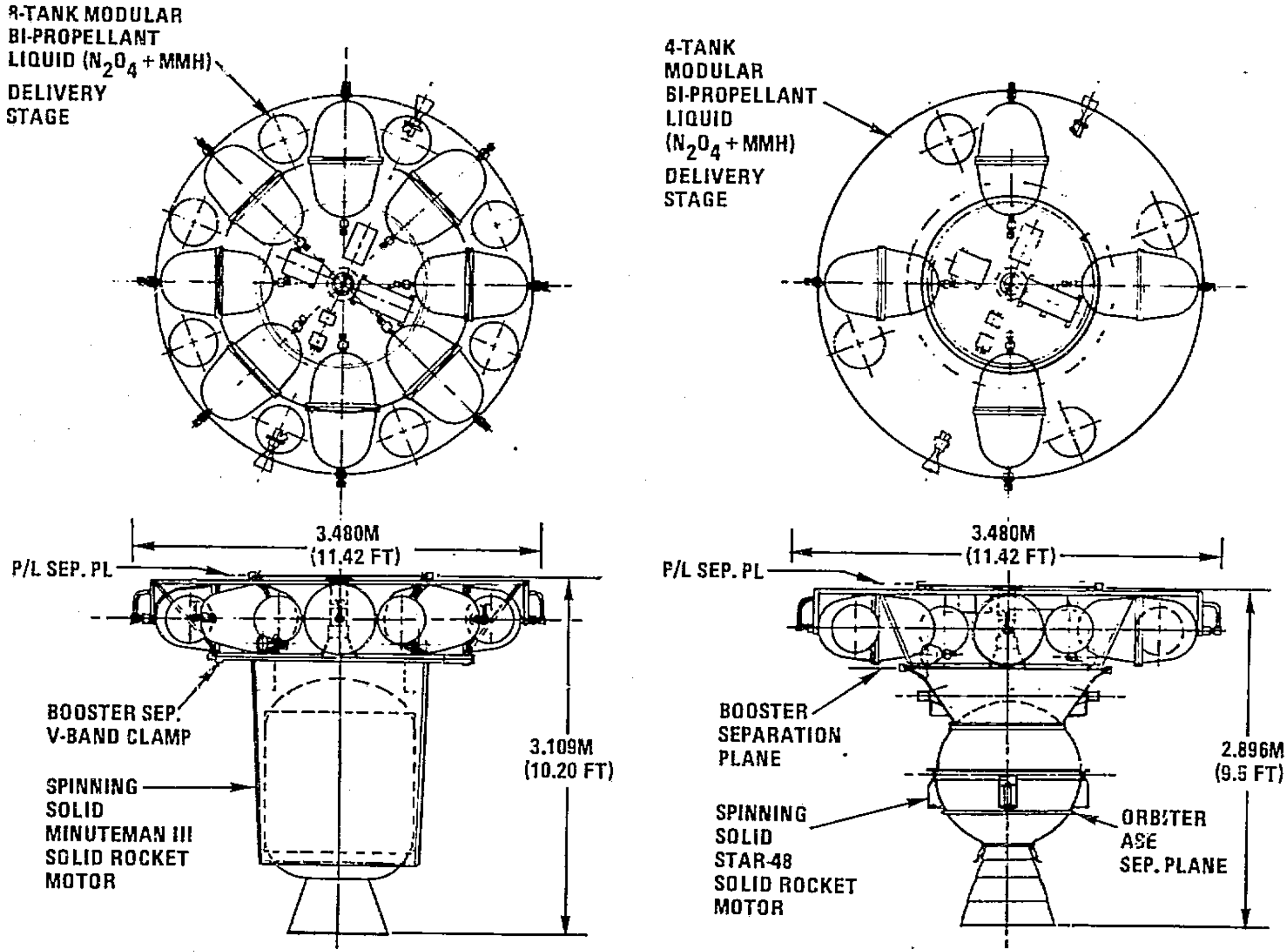



FIGURE 3.16 ADAPTATIONS OF EXISTING/PLANNED APPROACHES

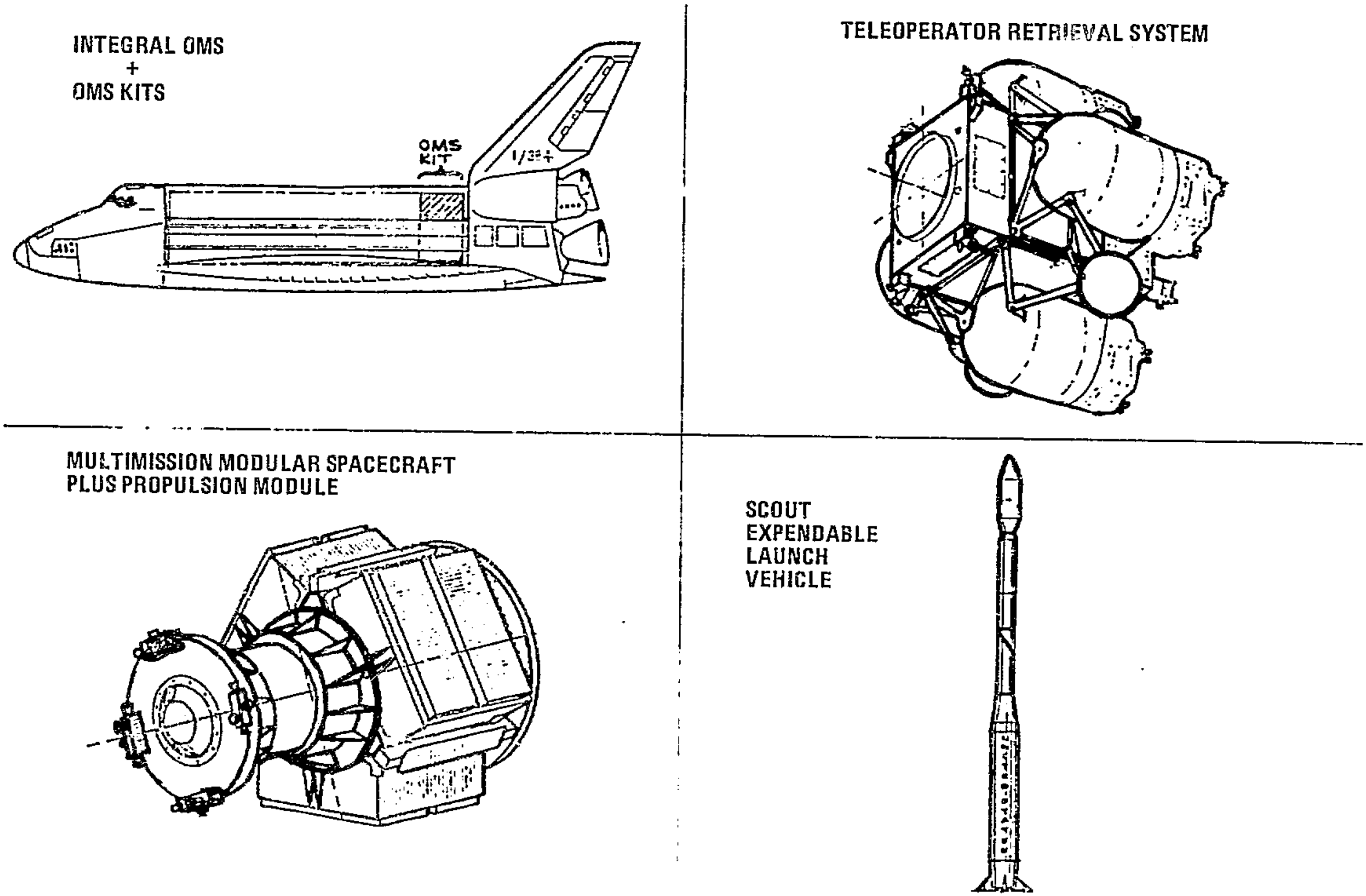



FIGURE 3.17 EXISTING/PLANNED LAUNCH APPROACHES

TABLE 3-XXXIII

SUMMARY OF PROPULSION APPROACHES FOR FURTHER EVALUATION

| ADAPTATIONS | NEW | EXISTING/PLANNED |
|---|---|---|
| MIII/MODULAR BIPROPELLANT<br>STAR 48/MODULAR BIPROPELLANT | MODULAR-BIPROPELLANT<br>MODULAR-MONOPROPELLANT | TRS<br>OMS<br>MMS<br>SCOUT |
| 2 | 2 | 4 |